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GENERAL ELECTRIC REVIEW

VOL. XXVIII, No. 9

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Schenectady, N. Y.

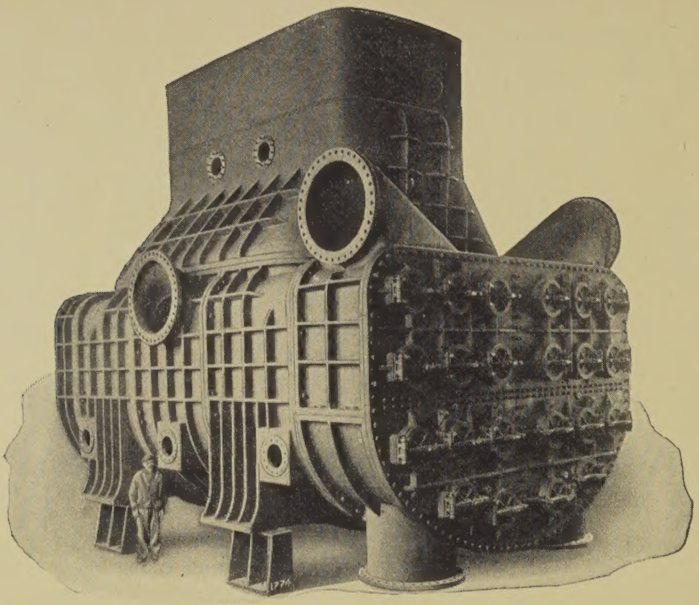
SEPTEMBER, 1925

TRANSPORTATION IN ITS MOST MODERN FORM

Flexibility, economy, smoothness and ease of control are the qualities inherent in this gas-electric driven motorbus, which belongs to a fleet of similar vehicles operated by the Philadelphia Rural Transit Company. The history and development of this phase of transportation are contained in the leading article of this issue

In This Issue:

Ballast Resistors
Resuperheating
Farming by Electricity
Automatic Railway Signals
Photographing 200,000,000 Cycles
Fluorescence
Gas-electric Motorbuses



THE 4TH WHEELER CONDENSER INSTALLED

For the Public Service Corporation, Newark, N. J. in 3 years

THIS 50,000 sq. ft. bowl-shaped condenser is to be installed with a 37,000-kw. turbine at the Kearney Station of the Public Service Corporation. Two multiple-element Wheeler Steam Jet Air Pumps will afford the maximum flexibility of air removal. The shallow tube bank and ample steam lanes give hot condensate temperature and high vacuum due to a minimum pressure drop across the tube bank.

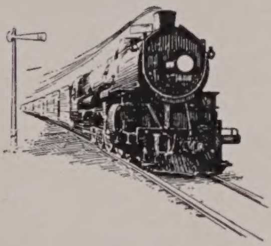
This design requires from four to five feet less head room than any other type of surface condenser.

WHEELER PRODUCTS INCLUDE

CONDENSERS - ALL TYPES
COOLING TOWERS - HEATERS
STEAM JET AIR PUMPS
HEAT EXCHANGERS
EXPANSION JOINTS
EVAPORATORS
BOILER FEED PUMPS
CENTRIFUGAL PUMPS
TURBINES
CONDENSER TUBES
BRASS & COPPER PIPE

WHEELER CONDENSER & ENGINEERING CO.
149 Broadway, New York
Works - CARTERET, N.J., NEWBURGH, N.Y.

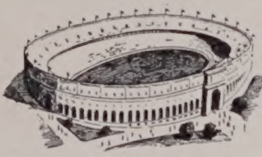
Stop



RAILROAD operation depends heavily on air brakes and block signals. These two essentials of safe operation for high speeds and heavy trains are provided by the Westinghouse Air Brake Co. and the Union Switch & Signal Company, both of which have made extensive use of Stone & Webster construction service for important additions to their plants.

Look

NEXT Fall will see the UNIVERSITY OF PITTSBURGH in possession of a splendid new STADIUM being built under the supervision of STONE & WEBSTER.



The seats are in two tiers fully enclosing the playing field and affording a capacity of 70,000. Mr. W. S. Hindman is Chief Engineer with Miss Marion K. Hindman assistant on architectural design.

Listen

THE President of The American Sugar Refining Company wrote the Victor Talking Machine Company: "We employed Stone & Webster, Inc., for the construction of our new Baltimore Refinery . . . I recommend them to you unreservedly." Victor employed us to build a new manufacturing building, to enlarge another building, to remodel the power house, and later to put up another building.

"His Master's Voice"

STONE & WEBSTER-built plants and structures are found everywhere filling a multitude of power, industrial and other uses. Whatever you make or do you can profit by our varied experience for your new construction.

STONE & WEBSTER

INCORPORATED

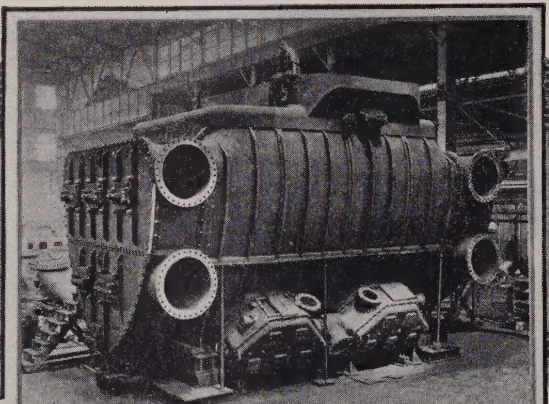
DESIGN · BUILD
OPERATE
FINANCE

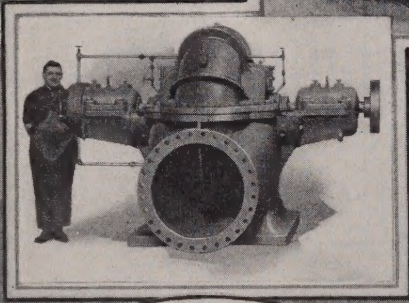
NEW YORK, 120 Broadway
SAN FRANCISCO, Holbrook Bldg.

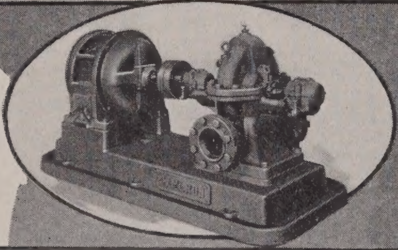
BOSTON, 147 Milk Street

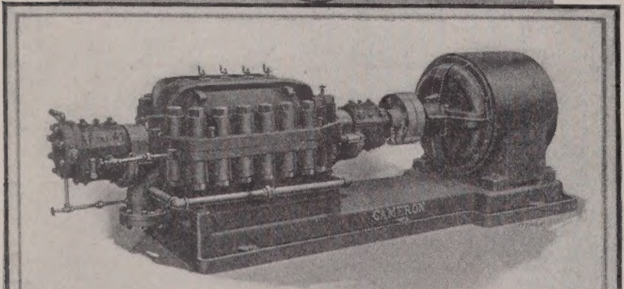
CHICAGO, 38 S. Dearborn Street
PHILADELPHIA, Real Estate Trust Bldg.

Produce Power with Greater Reliability and Lower Costs









Ingersoll-Rand Surface Condensers
Cameron Pumps

THE Ingersoll-Rand Surface Condensers have far less tube surface than other machines for the same vacuum, load and water temperatures. This means a saving in your maintenance and operating cost.

This marked decrease in surface has resulted from a careful co-ordination of many new features, as arrangement of tubes in stages—heart-shape shell—external devaporizer coolers—higher water velocities in single-pass construction, without higher friction.

Cameron circulating, condensate, and boiler feed pumps are designed to meet the hardest conditions in modern service. Every detail has been worked out with the chief idea in mind—DEPENDABILITY.

Bulletin 9036 on request

INGERSOLL-RAND COMPANY, 11 BROADWAY, NEW YORK CITY
Offices in principal cities the world over.
FOR CANADA REFER
CANADIAN INGERSOLL-RAND CO., LIMITED, ST. JAMES STREET,
MONTREAL, QUEBEC.

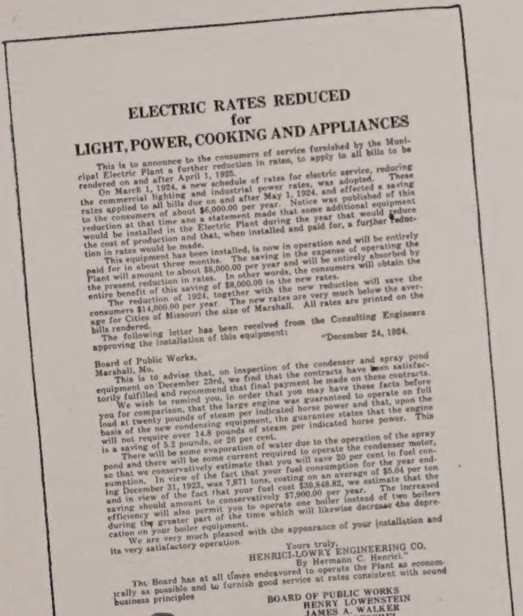
Ingersoll-Rand

A. S. CAMERON STEAM PUMP WORKS

Say you saw it advertised in the GENERAL ELECTRIC REVIEW

Marshall, Mo., Electric Consumers Saved Money on This Condenser

THE Municipal Electric Plant at Marshall, Mo., recently announced a reduction in electric rates effective April 1st. The reduction was made possible by the installation of new equipment—an Elliott-Ehrhart Low Level Jet Condenser with spray pond, which is saving operating expense conservatively figured at $8,000.00 per year.



ELECTRIC RATES REDUCED
for
LIGHT, POWER, COOKING AND APPLIANCES

This is to announce to the consumers of service furnished by the Municipal Electric Plant a further reduction in rates, to apply to all bills rendered on and after April 1, 1925.

On March 1, 1924, a new schedule of rates for electric service, reducing the commercial lighting and industrial power rates, was adopted. These rates applied to all bills due on and after May 1, 1924, and effected a saving to the consumers of about $6,000.00 per year. Notice was published of this reduction at that time and a statement made that some additional equipment would be installed in the Electric Plant during the year that would reduce the cost of production and that, when installed and paid for, a further reduction in rates would be made.

This equipment has been installed, is now in operation and will be entirely paid for in about three months. The saving in the expense of operating the Plant will amount to about $8,000.00 per year and will be entirely absorbed by the present reduction in rates. In other words, the consumers will obtain the entire benefit of this saving of $8,000.00 in the new rates.

The reduction of 1924, together with the new reduction will save the consumers $14,000.00 per year. The new rates are very much below the average for Cities of Missouri the size of Marshall. All rates are printed on the bills rendered.

The following letter has been received from the Consulting Engineers approving the installation of this equipment:

"December 24, 1924.

Board of Public Works,
Marshall, Mo.

This is to advise that, on inspection of the condenser and spray pond equipment on December 23rd, we find that the contracts have been satisfactorily fulfilled and recommend that final payment be made on these contracts.

We wish to remind you, in order that you may have these facts before you for comparison, that the large engine was guaranteed to operate on full load at twenty pounds of steam per indicated horse power and that, upon the basis of the new condensing equipment, the guarantee states that the engine will not require over 14.8 pounds of steam per indicated horse power. This is a saving of 5.2 pounds, or 26 per cent.

There will be some evaporation of water due to the operation of the spray pond and there will be some current required to operate the condenser motor, so that we conservatively estimate that you will save 20 per cent in fuel consumption. In view of the fact that your fuel consumption for the year ending December 31, 1923, was 7,871 tons, costing on an average of $5.04 per ton and in view of the fact that your fuel cost $39,848.82, we estimate that the saving should amount to conservatively $7,900.00 per year. The increased efficiency will also permit you to operate one boiler instead of two boilers during the greater part of the time which will likewise decrease the depreciation on your boiler equipment.

We are very much pleased with the appearance of your installation and its very satisfactory operation.

Yours truly,
HENRICI-LOWRY ENGINEERING CO.
By Hermann C. Henrici."

The Board has at all times endeavored to operate the Plant as economically as possible and to furnish good service at rates consistent with sound business principles

BOARD OF PUBLIC WORKS
HENRY LOWENSTEIN
JAMES A. WALKER
PAUL GROESCHEL
WILLIAM F. FISHER

The consulting engineers — Henrici-Lowry Engineering Co., in a letter approving the installation, quote figures which show that the new condensing equipment is netting a saving of 5.2 pounds of steam per indicated horsepower—or a saving of 26%. On a fuel consumption of 7,871 tons for 1923, costing $5.04 per ton, a conservative figure of 20% amounts to $7,900 per year. The increased efficiency permits operating one boiler instead of two boilers during the greater part of the time. Actual operating records for the three months since the Condenser has been installed indicate a coal consumption of 5.23 pounds per kilowatt-hour, as against 7.57 in 1923.

The Elliott-Ehrhart Condenser serves three engines, one 750 kv-a., one 375 kv-a. and one 250 kv-a. The Condenser is so piped that any of the engines may be run on the Condenser.

ELLIOTT COMPANY

GENERAL SALES OFFICES AND WORKS
JEANNETTE, PA.
DISTRICT OFFICES: ATLANTA, BALTIMORE, BOSTON, CHICAGO, CINCINNATI, DETROIT, CLEVELAND, NEW YORK, KANSAS CITY, PHILADELPHIA, PITTSBURG, ST. LOUIS, SYRACUSE

EXECUTIVE OFFICE—PITTSBURGH, PA.
PRODUCTS
CONDENSERS, AIR EJECTORS, FILTERS, DEAERATORS, STRAINERS, SEPARATORS, GREASE EXTRACTORS, AUTOMATIC VALVES, BLOW-OFF VALVES, HEATERS

C-274

Elliott-Ehrhart Condensers

express every refinement of the art

McINTOSH & SEYMOUR DIESEL ENGINES

Exceptional service from these two units sold a third to the same owners

REPEAT orders prove merit!

Performance entirely in accord with the McIntosh & Seymour standard has made these two 575-b.hp. Diesel Engines so satisfactory that the owners (name on request) have purchased an additional unit for use in one of their other plants.

If you need more power, or pay too much for generating what you already use, the advice of our engineers would cost you nothing, but might show astonishing possibilities.

McINTOSH & SEYMOUR
CORPORATION
Main Office and Works: AUBURN, NEW YORK

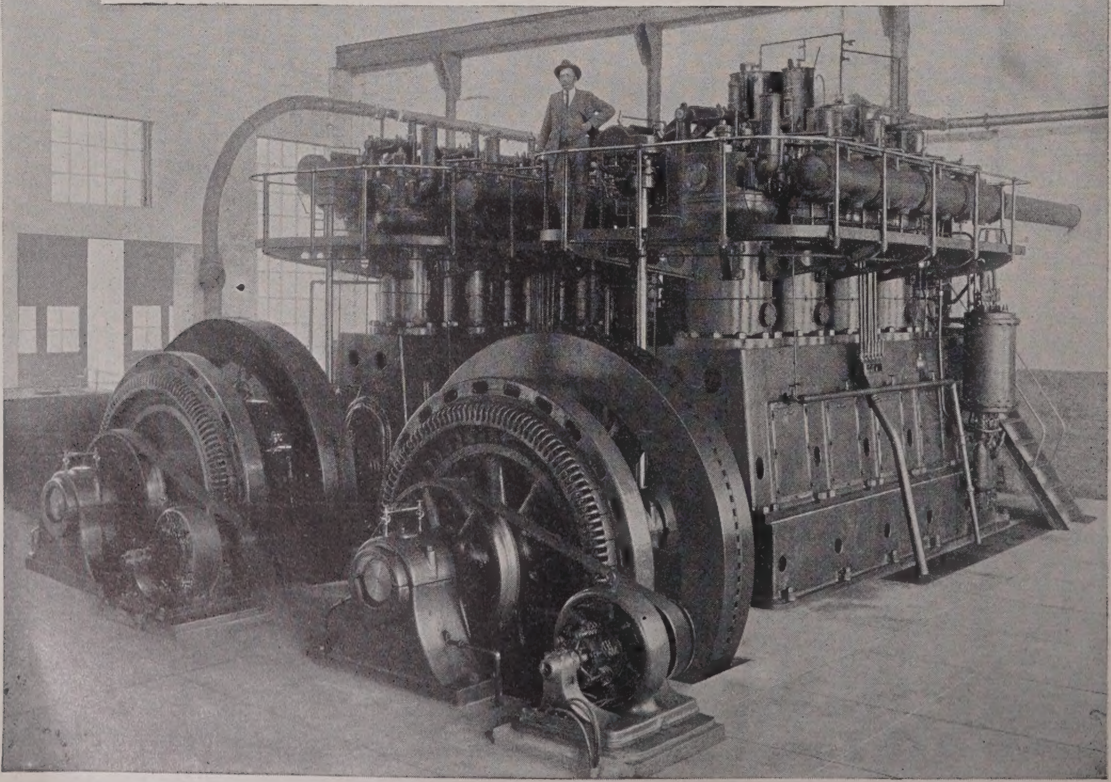
New York City
149 Broadway

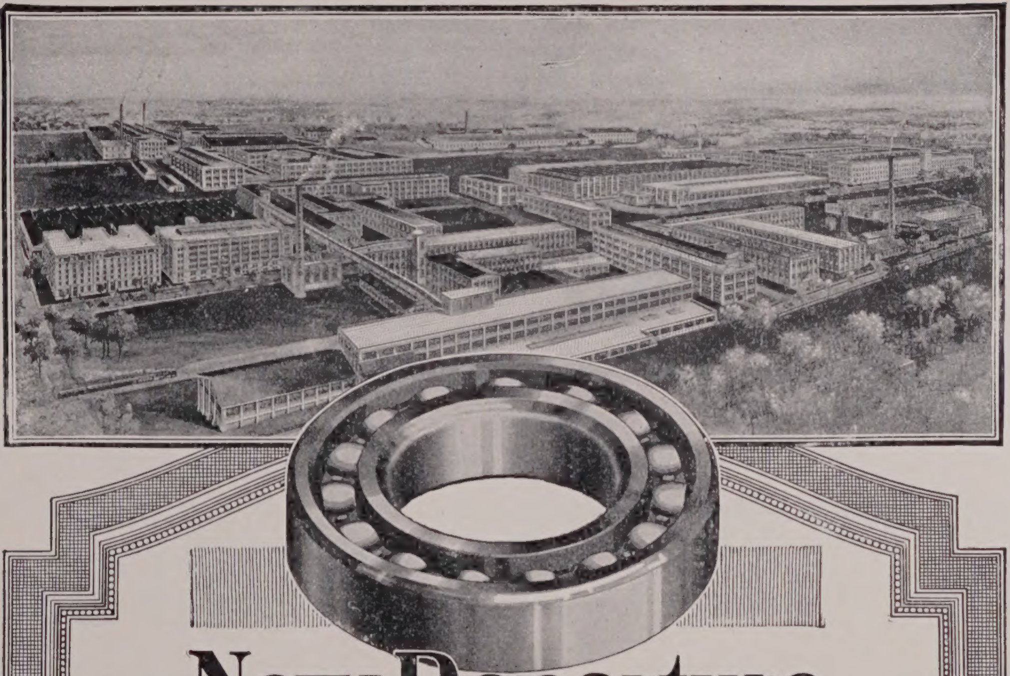
Jacksonville, Fla.
412 Bisbee Bldg.

Houston, Texas
317 Humble Bldg.

Kansas City, Mo.
1016 Baltimore Ave.

San Francisco
815 Sheldon Bldg.





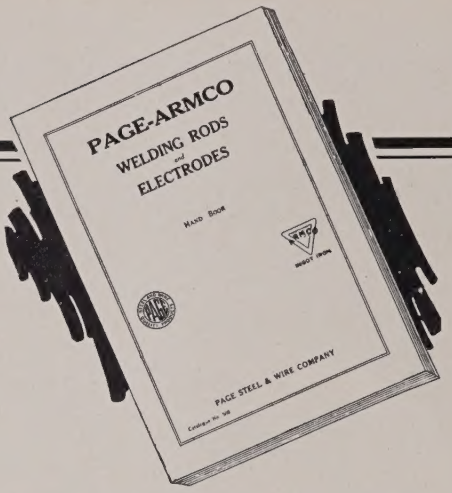
New Departure Ball Bearings

New Departures Outsell Because New Departure Excels in:

1. **Experience.** One of the oldest manufacturers of ball bearings and steel balls in America.
2. **Modernity of plant equipment and processes.** 82 buildings, 39 acres floor space, machinery modern in every respect—much of it developed by our own engineers.
3. **Plant operation and capacity to deliver.** 32,000 tons of steel are used in producing 27 million quality ball bearings a year.
4. **Heat treating plants.** 392 heat treating furnaces, each with pyrometer control. 157,524 sq. ft. of floor space.
5. **Forge plant.** 40 upset forging machines, 12 drop hammers, 149 auxiliaries, 69 furnaces, 21,000 tons capacity a year, 133,328 sq. ft. floor space.
6. **Grinding plants.** 1435 machines of most modern design covering 269,305 sq. ft. of floor space.
7. **Steel ball plant.** 1179 machines, most of which are of special New Departure design. 105 furnaces, 249,461 sq. ft. of floor space. 300 million steel balls of all sizes per year.
8. **Inspection.** Begins at steel mills and from then on to the finished product, includes every known metallurgical and mechanical examination during and after every operation.
9. **Research.** Extensive research and experimental laboratories.

THE NEW DEPARTURE MFG. CO., BRISTOL, CONN., DETROIT, CHICAGO.

192



Send for this free Welding Hand Book

It shows how to test the quality of welding wire and electrodes—how important is the choice of the right filler for each class of work—why Page products are the best that scientific methods can produce, and other valuable welding information.

Remember this—Page supplies the correct grade of wire and electrodes for *any* job—Page Mild Steel Gas Welding Wire and Electrodes, Page-Armco Special Processed Wire and Electrodes and Page High Carbon Wire and Electrodes. You cannot be too particular about the selection of your welding metal.

Mail the coupon for this book and the facts—today.

PAGE

Mild Steel : PAGE-ARMCO : Page High Carbon
Gas Welding Wire *and* Electrodes

PAGE STEEL & WIRE COMPANY
An Associate Company of the American Chain Company, Inc.
Bridgeport, Connecticut
District Offices: New York Pittsburgh Chicago San Francisco

Page Steel & Wire Co.,
Bridgeport, Conn.

Gentlemen:
Please send me a free copy of your Welding Hand Book. This is to incur no obligation.

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Address ....

Correct
National Pyramid Brushes

—for all operating conditions

BY MEETING correctly the conditions in numerous individual installations, National Pyramid Brushes have saved thousands of dollars for industrial plants, central and substations, trolley and rail lines.

When you have a troublesome brush problem, we will gladly assist you in solving it.

Our Sales Engineers are always at your service.

Manufactured and guaranteed by

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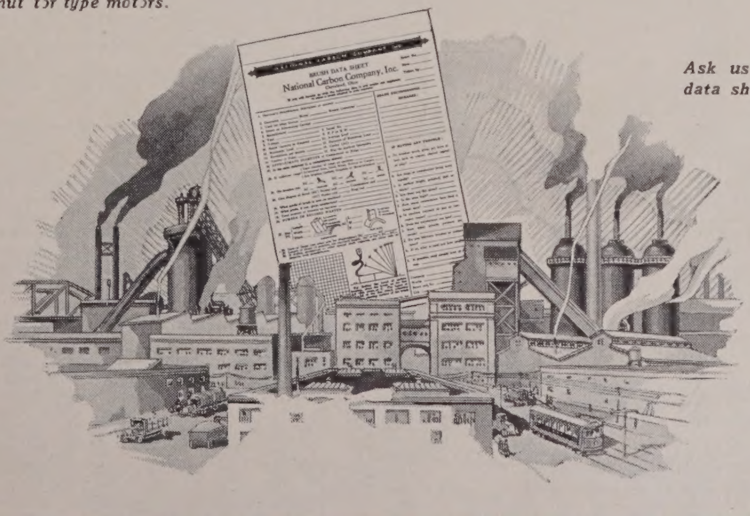
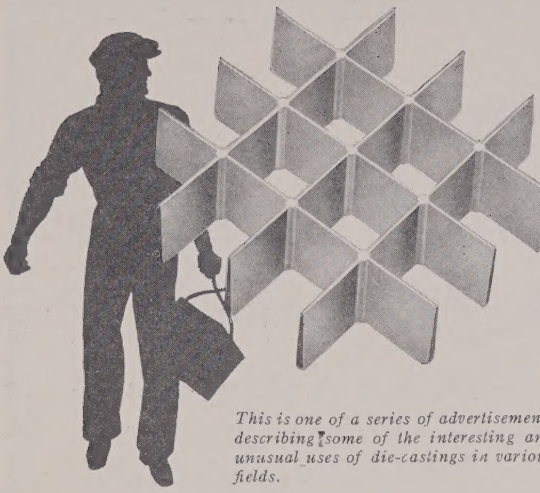
Barker Place
Phone: ATLantic 3570

NEW YORK, N. Y.
357 West 36th St.
Phone: LACkawanna 8153

Where heavy starting torque or speed control is necessary, consider the advantages of commutator type motors.



Ask us about our data sheet service.



This is one of a series of advertisements describing some of the interesting and unusual uses of die-castings in various fields.

Die-casting a form for the modern ice-man

GONE forever from the back door of many homes is the lusty voice that calls, "Any ice today, lady?" The man with the tongs is losing customers to the modern ice-man—the electrical refrigerator.

In addition to keeping things always cool, the modern ice-man delivers little blocks of ice which are frozen in a form or mold like the one illustrated. This form is die-cast and is another outstanding example of how die-castings are being utilized in modern inventions.

New inventions are by no means, however, the only places where die-castings are being used to advantage. Of aluminum, zinc, tin and lead alloys, we are die-casting parts also for many machines and appliances which have been on the market for years.

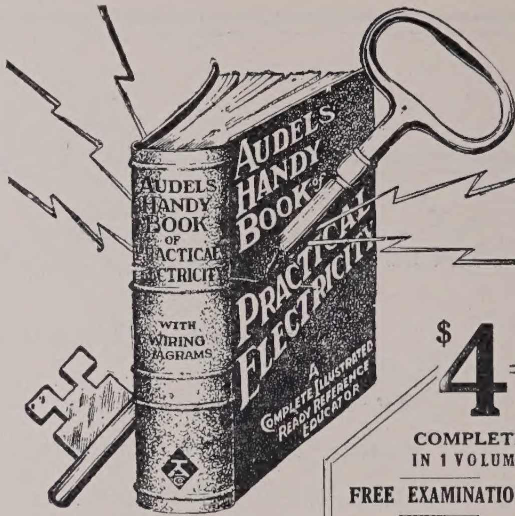
Whether you have a new product or an old one, we should like to have you consider with us the possibility of die-casting some of its parts. Our experienced technical staff is at your service.

When you buy die-castings from us, you are assured of the same high quality that has established our Dutch Boy trademark as a mark of excellence on babbitts, solder and paint materials.

NATIONAL LEAD COMPANY
Die-Casting Division
111 Broadway New York, N. Y.

Western Representatives: E. R. McCormick, 2599 Cadillac Ave., Detroit, Mich. A. H. Bergedick, 667 Bowen Street, Dayton, Ohio. A. A. Gildemeister, 444 Fourth Street, Toledo, Ohio.

ALUMINUM, ZINC, LEAD *and* TIN
DIE-CASTINGS


AUDELS HANDY BOOK OF PRACTICAL ELECTRICITY
WITH WIRING DIAGRAMS
AUDELS HANDY BOOK of PRACTICAL ELECTRICITY
A COMPLETE ILLUSTRATED READY REFERENCE EDUCATOR

$4
COMPLETE IN 1 VOLUME
FREE EXAMINATION
$1 PER MONTH IF SATISFIED

AUDELS HANDY BOOK

OF PRACTICAL ELECTRICITY

INFORMATION

On every electrical subject arranged in HANDY FORM under these headings:—

Electro-Therapeutics — Electric Shocks — X-Rays — Welding — Brazing — Soldering — Heating — Motion Pictures—RADIO—Radio Hook-ups—Telephone—Telegraph — Electric Bells — Cranes — Elevators — Pumps — Electric Ship Drive—Electric Railways—Electric Vehicles.

Automobile Starting and Lighting System—Ignition—Generation and Transmission—Electric Tools — Plant Management — Power Station Plans — ARMATURE WINDING—Armature Repairing —A.C. Motors—Alternator Construction — Alternators — D. C. Motors—Dynamos—Magnetic Induction—WIRING—Wiring Diagrams—Electric Lighting—Sign Flashers—Cable Splicing—Power Wiring—Underground Wiring—Outside Wiring—Wiring Finished Buildings—Tests.

A. C. Apparatus (Switch Devices; Current Limiting; Lightning Protection)—Rectifiers—Converters — Transformers — Power Factor — Alternating Currents — D. C. Apparatus (Switches; Fuses; Circuit Breakers; Rheostats; Watthour Rules) — Electro Plating — Electrolysis — Storage Batteries — Magnetism — Electrical Energy — Conductors — Insulators — Static Electricity — Dynamic Electricity — Magnetic Electricity —Radio Electricity—Recent Applications — Ready Reference — Index on all subjects

Here is an up-to-date, quick Ready Reference. It gives complete instruction and inside information on every electrical subject. Every point clearly explained in plain language and diagrams that are easily understood. Handy to use. Easy to learn from. Subjects arranged in progressive manner for the student and with complete index which gives information instantly to professional workers. A time saver, money saver, and a helping hand for Engineers, Professional Electricians, Students and all interested in electrical work.

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Audels Handy Book is a magnificent volume that you will be proud to own and carry with you. Gilt Edged. Durable real leather binding. 1040 pages of strong white paper. Large Type. 2600 illustrations and diagrams. A mine of information and a most unusual value at only $4.

Send no money. Pay nothing to postman.

Use this coupon, *NOW!*

FREE EXAMINATION COUPON

Theo. Audel & Co., 65 West 23rd St., New York

Please send me AUDELS HANDY BOOK OF PRACTICAL ELECTRICITY for *free examination.* If satisfactory, I will send you **$1** in 7 days, then **$1** monthly until **$4** is paid.

Name..............................

Address..............................

Occupation..............................

Employed by ....GE

cross section them
any where!
you'll find them uniform

The close grained even texture of all STACKPOLE Brushes is the result of over 18 years of research by Stackpole Engineers and Chemists, combined with the scientific control maintained through every step of their manufacture.

The exceptionally long life of Stackpole Brushes and their efficient functioning under all conditions make friends for Stackpoles wherever applied.

Our Engineers will be glad to help you in the proper selection of your Carbon Brushes - be they brushes for vacuum cleaner motors or brushes for central station equipment.

Write for catalogue

Stackpole carbon brushes

STACKPOLE CARBON COMPANY, ST. MARYS, PA.

Steadfast Purpose

THE most essential element of economical production and service in any field of industry is specialization From its earliest conception The Maqua Company was organized with a steadfast purpose in view—*Service to the electrical industry*.

The requirements of such a clientele are exacting and wide in scope. We have been successful in meeting the demand through the untiring efforts of a force of craftsmen especially trained to produce high-grade commercial and technical printing.

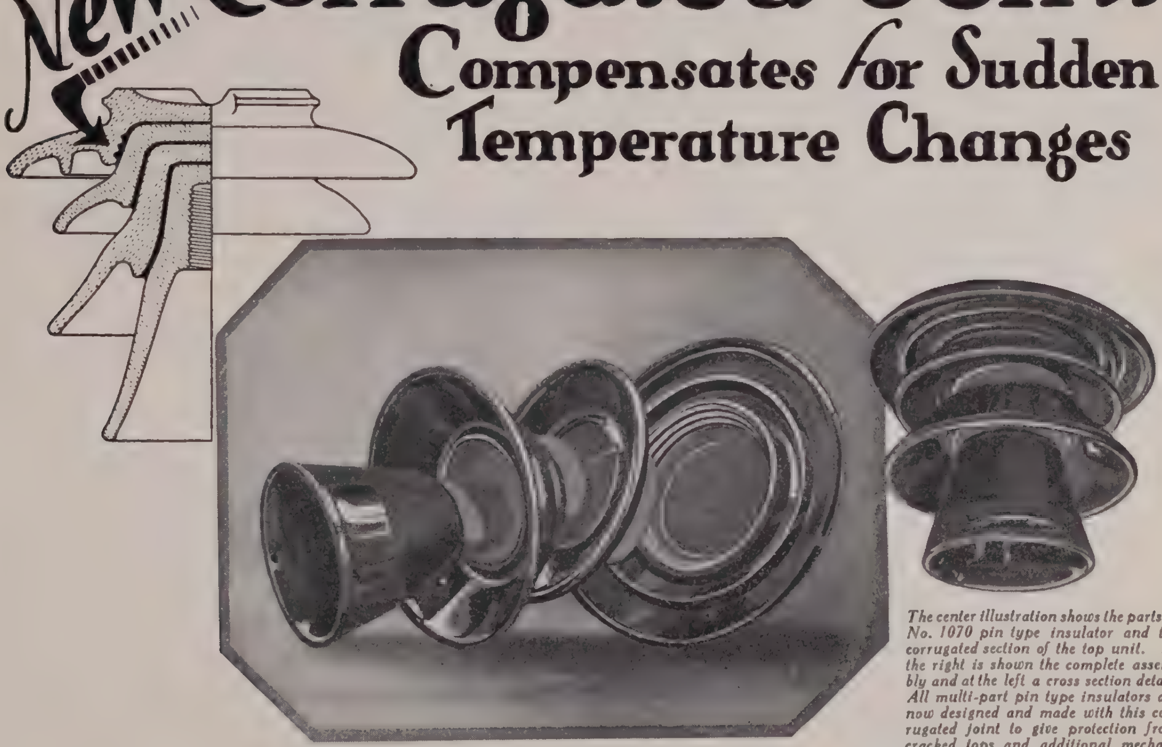
For more than a decade The Maqua Company has been supplying service to manufacturers and dealers in electrical supplies and machinery. And when we mention *Service* to the buyers of printing we feel confident the word carries with it the prestige of prominence in the production of business-building printing.

THE MAQUA COMPANY

Offices and Plant located at SCHENECTADY, NEW YORK

PRINTERS, ENGRAVERS and BINDERS to the ELECTRICAL INDUSTRY

The New Corrugated Joint Compensates for Sudden Temperature Changes



The center illustration shows the parts of No. 1070 pin type insulator and the corrugated section of the top unit. At the right is shown the complete assembly and at the left a cross section detail. All multi-part pin type insulators are now designed and made with this corrugated joint to give protection from cracked tops and additional mechanical strength.

MULTI-PART PIN TYPE insulators can now be obtained which are insured from damage to the top porcelain unit due to sudden temperature changes. These new Locke designs incorporate radical improvements in construction and method of assembly which effectively correlate the required mechanical strength with high resistance to thermal stresses.

The distribution of the mechanical load is so equalized that no concentrated stresses can be set up in any part of the porcelain. These tests have shown this new construction possesses exceptional strength, as well as having the necessary flexibility to provide for the most extreme temperature changes which could be encountered in service.

LOCKE INSULATOR CORPORATION

BALTIMORE, MD. Factories at Victor, N. Y., and Baltimore, Md.

Sales Offices:

Boston, Mass.
84 State St.
New York, N. Y.
120 Broadway
Victor, N. Y.

Philadelphia, Pa.
803 Atlantic Bldg.
Dallas, Texas
1801-15 No. Larmar St.

Chicago, Ill.
770 Illinois Merchants Bank Bldg.
Atlanta, Ga.
414 Red Rock Bldg.

Salt Lake City, Utah
P. O. Box 1877
Denver, Colo.
819 Seventeenth St.

San Francisco, Calif.
575 Mission St.
Los Angeles, Calif.
236 S. Los Angeles St.

Portland, Oregon
61 Fifth St. No.
Seattle, Wash.
570 Fifth Ave. So.

Export Agents: International General Electric Co., Schenectady, N. Y.

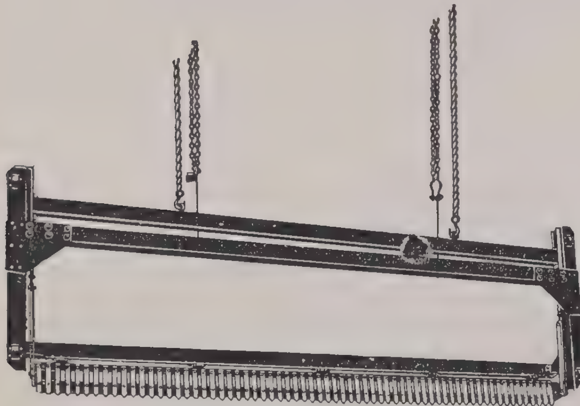
LOCKE

PORCELAIN

Say you saw it advertised in the GENERAL ELECTRIC REVIEW

NEWPORT NEWS RACK RAKE

WILL SOLVE YOUR TRASH PROBLEMS



Newport News Rack Rake in lowering position

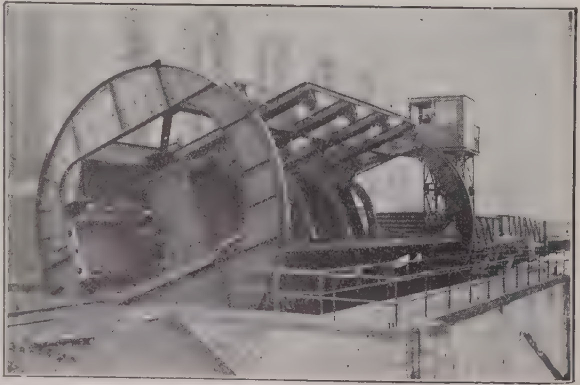
How much tribute in the form of lost power and extra employees will you pay this fall to floating and submerged trash?

Write for full information about the Newport News Mechanically-operated Rack Rake, to suit your needs

NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY

DEPT. G.E. **NEWPORT NEWS, VA.**

Latest Development in Revolving Car Dumpers



RECENT PURCHASERS

By-Products Coke Corporation
Cleveland Electric Illuminating Co.
The Koppers Co. for Bethlehem Steel Co.
The Koppers Co. for Commonwealth Edison Co. (2 Plants)
Utah Copper Company (2 Machines)
Chile Exploration Company (2 Machines)

It meets the demand for a dumper of simple construction, small investment, high efficiency, low operating cost and a minimum of labor.

Built in lengths of 30, 40, 50 and 60 feet for handling cars from 6 ft. 6 in. to 13 ft. 0 in. high and from 9 ft. 0 in. to 10 ft. 9 in. wide and loaded capacities up to 320,000 lbs. gross weight.

The Wellman-Seaver-Morgan Company
Cleveland, Ohio, U. S. A.

In the heart of the Hell Gate Station-

Section of bus bar panel board Hell Gate Station. Anaconda Copper is used.

Uniform in dimension throughout their entire length, Anaconda Bus Bars provide the accurate electrical capacity so important in central station operation.

Anaconda Bus Bars are cold drawn through dies. This process assures accurate dimensions and flat contact surfaces.

The degree of hardness is also carefully controlled, so that Anaconda Bus Bars are easily bent and retain the required form.

The use of Anaconda Electrolytic Copper guarantees a conductivity of 99% or better at 20° C in terms of International Annealed Copper Standard.

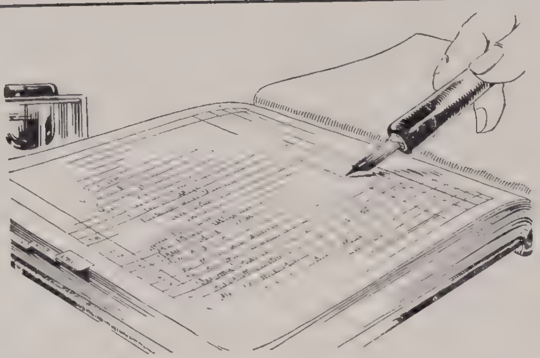
ANACONDA
from mine to consumer

Copper Wire and Cable
(Bare and Insulated)
Bus Bars & Tubes
Condenser Tubes
Commutator Segments
Drawn Copper Shapes
Welding Rods

Copper, Brass and
Nickel Silver
Sheets, Wire, Rods
and Tubes

THE AMERICAN BRASS COMPANY
GENERAL OFFICES: WATERBURY, CONNECTICUT
Sales Offices and Agencies in Principal Cities
Canadian Mill: ANACONDA AMERICAN BRASS LIMITED, New Toronto, Ontario.
World's foremost manufacturers of Copper, Brass,
Bronze and Nickel Silver

ANACONDA BUS BAR COPPER



Double-Barreled Economy

THE first kind of economy you effect in purchasing good grease can be compared to the saving in buying one automobile tire at $20.00, good for 15,000 miles, instead of buying two at $15.00 each, good for a total of 15,000 miles, maybe. High-class grease does cost less in the long run than cheap stuff.

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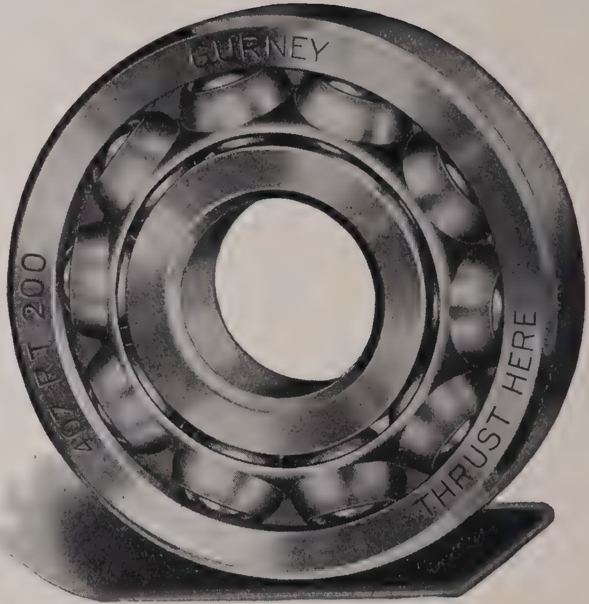

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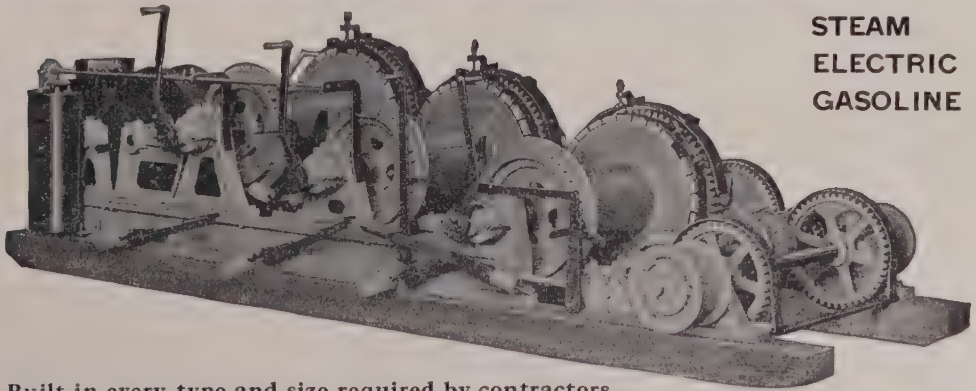

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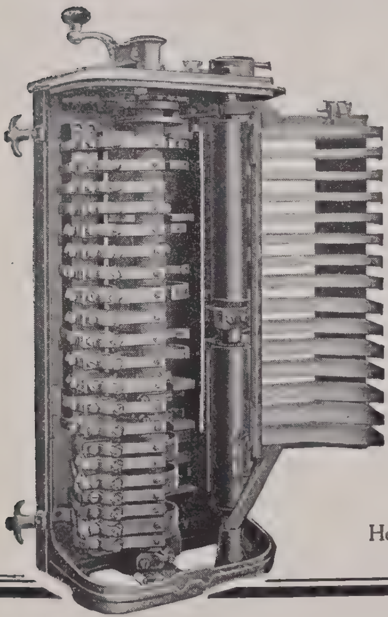

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE   Editor, JOHN R. HEWETT   Associate Editor, E. C. SANDERS

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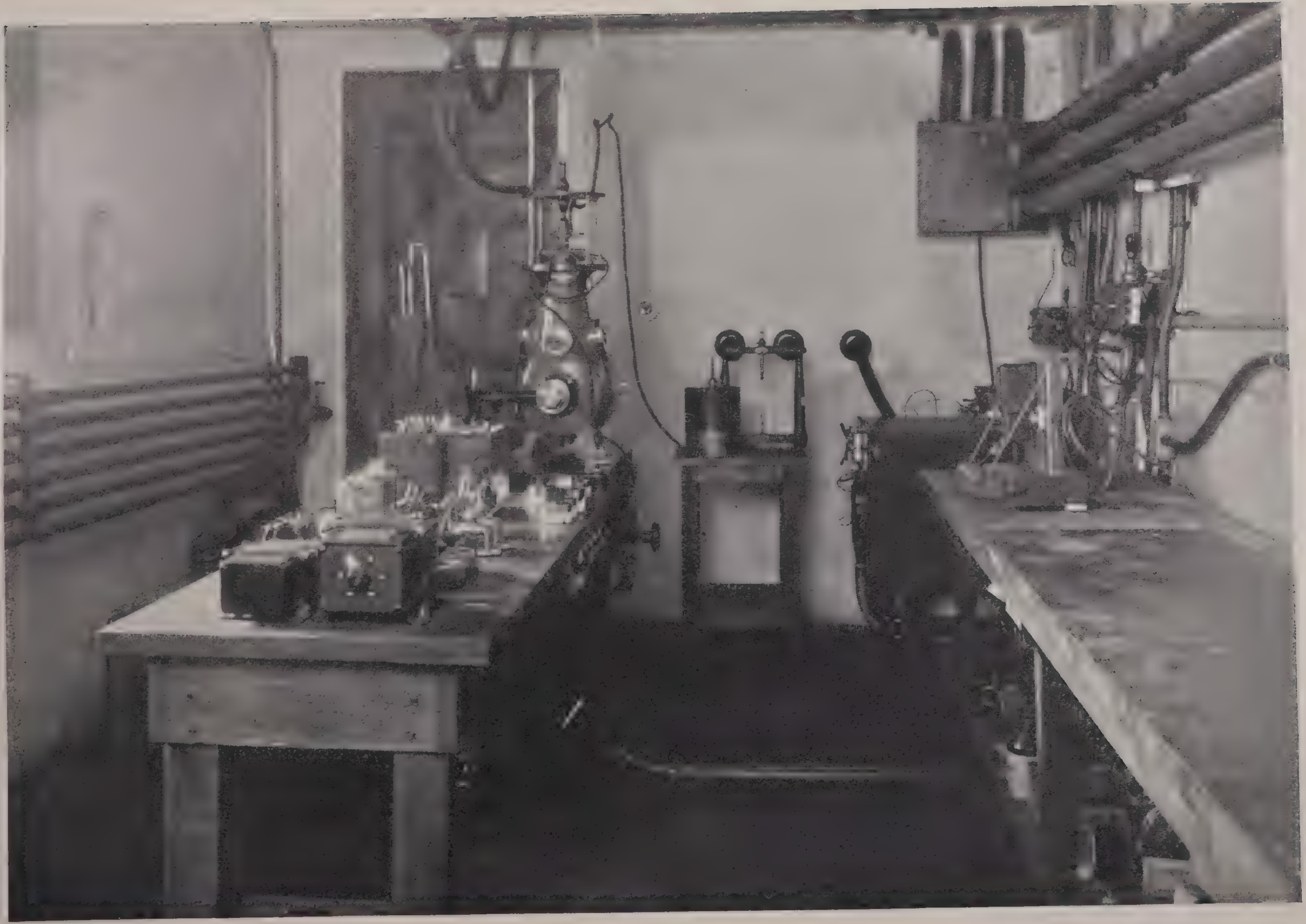

WHERE THE MICRO-SECOND IS A QUARTER OF AN INCH LONG

The laboratory set-up of the Dufour high-frequency oscillograph, arranged for photographing the time-lag characteristics of the needle-gap. The Dufour instrument, adapted to this use by Messrs. McEachron and Wade, is a form of cathode tube in which the photographic film is placed within the evacuated space.

The article describing their experiments is on page 618

GENERAL ELECTRIC REVIEW

OVER A SPAN OF INCHES OR MILES, ELECTRICITY SERVES

The place where power is needed is seldom the place where it can be generated to best advantage, and the intervening span over which energy is transmitted may measure but a few inches or many miles. If the separation is of the latter order there is no other choice than electricity as the form of transmission, and fortunately no other choice is needed so well does electricity serve the purpose.

When the problem involves but a short span the possibilities of mechanical transmission are so numerous that regard is commonly given to this system of transmission only, no matter how great a transformation of the power characteristics may be required. That notable success has been attained in developing mechanical drives to accomplish some of these transformations is indeed a tribute to the engineers of that profession. Nevertheless, mechanical transmission has rather definite limitations in flexibility of application and operation. The lack of sufficient application flexibility may readily prevent utilizing some type of prime mover that generates horsepower-hours cheaply but of a speed-torque characteristic widely different from that required by the load. The lack of sufficient operating flexibility may handicap the best performance of the driven machine in case variable speed is an essential.

Thus there are instances of short-span power transmission where electricity offers decided advantages, not because the ends cannot be linked by other means as in the case of the miles-long transmission line but because it introduces practically unlimited flexibility of application and of operation.

On shipboard it is found worthwhile to replace the low-speed reciprocating engine by the more economical high-speed turbine, or Diesel engine, convert its output to electricity, and reconvert to mechanical power only a few feet away. Even over a span of as many inches, conversion and reconversion is not necessarily superfluous as is demonstrated in the case of the automobile bus where it affords an opportunity to obtain better inherent speed control than is possible with the throttle-clutch-gearshift combination.

But few of us who drive pleasure cars give thought to the mechanical system of speed control as the sources of a number of our troubles; if the car is slow to accelerate in traffic, we place the blame on the engine; if the engine stalls, we again blame it for being weak; if the fuel that is fed is not completely utilized at times of forced acceleration or heavy pulling in high gear, we impute the fault to improper carburetor adjustment; if we race the engine—well, it's ours anyhow and we are not responsible to anyone else for the higher maintenance cost we incur. All these "ifs," however, are of vital consideration to the bus operator for with him driving is a matter of business, a business of furnishing as rapid a schedule of service as city or interurban traffic conditions will safely permit and at an operating cost sufficiently low to assure him a reasonable profit in competition with other lines of transportation.

By replacing the clutch and gear shift box with an electric generator, an inches-long transmission system, and an electric motor he can eliminate the common shortcomings of driving technique mentioned in the preceding paragraph.

An interesting historical review of the developments leading up to the present-day gas-electric bus, together with detailed information about the equipment, is furnished by Mr. Baldwin on page 608. E. C. S.

An Electric Drive for Gasoline-propelled Motorbuses

By Henry S. Baldwin

Automotive Engineering Department, General Electric Company

The motorbus as a practical conveyance fills two needs in our urban transportation problem. Either it may serve as a feeder for existing traction lines or it may be used on restricted highways that are not open to trolley lines. To be economical in operation the motorbus must have a large passenger carrying capacity and hence must itself be large. The ordinary transmission system of the automobile or truck with its friction clutch is not suitable for the frequent starting and stopping required of a large bus. When electric drive is used as the connecting link between the motor and the rear wheels we eliminate the troublesome transmission of the ordinary motorbus and in addition obtain uniform acceleration. In this article, presented as a paper before the semi-annual meeting of the Society of Automotive Engineers, the author begins with a description of the first experiment in electric drive in 1904, and follows the course of its progress to the present time.—Editor.

By a singular coincidence, two new industries had their beginning about 30 years ago. The practical use of electricity in the affairs of man and the appearance of the automobile a little later were destined together to exert a great influence on modern civilization. The rapid growth of these two forces has been unique; today they stand among the first of the great industries. Both represent the latest creations of the human mind. The use of electricity has enabled manufacturers to meet the demands of the public in the production of the automobile.

Although electricity had been employed for many years for the purpose of ignition, it was not until 1911 that it was adopted commercially for starting the internal-combustion engine and for lighting the automobile. Without doubt, this single innovation, more than any other, served to bring about the great popularity of the gasoline automobile, for it removed forever the necessity for physical exertion in starting the engine and at the same time simplified the lighting problem.

Few realize, perhaps, that the regular electrical equipment of a passenger car embodies, on a small scale, almost every device known to the art for the generation, control, measurement, storage and use of electrical energy. A recent study has disclosed the somewhat surprising fact that 5 per cent of the weight and nearly 10 per cent of the selling price of a five-passenger sedan represent the electrical apparatus that the public considers necessary for its comfort and convenience.

Until the appearance of the motorbus a few years ago, practically all transportation of passengers in cities and suburbs was carried on by electric street-railways with overhead or underground trolleys and, as a result, this system has reached a state of high development and organization, of low operating-cost and high efficiency. It is safe to say that, for heavy city traffic, where unlimited power, high acceleration and large carrying-capacity are needed, the electric street-railway can easily hold its own. Public utility companies, however, have not been slow to realize that the new conditions which have arisen within the last few years have greatly affected the problem of passenger transportation. These, briefly, are the serious traffic congestion caused by the ever-growing number of private automobiles and motor trucks and the rapid and successful development of the motorbus with its freedom from the restraint of rails and trolleys. Here is a new point of contact between the great electrical development that has been going on for many years and the automotive industry. Fortunately, the public utility companies, with their city franchises and long experience in handling passengers safely, comfortably and cheaply, have realized the significance of the motorbus; and, on the other hand, the motorbus manufacturer is keenly alive to the possibilities of a new field for his product.

Two factors in the transportation world are now working together to give the public the best and most acceptable service; the public utility company must look to the motorbus to act as a feeder and to relieve the pressure of traffic by utilizing the great boulevards and motor highways on which rails and trolley wires are not permitted. The experience of street-railway companies in the successful use of electric motors and control, covering a long period of years under all conditions of traffic and in all seasons, has established great confidence in their reliability and durability. It is this experience that has led the utilities to a serious consideration of the electric drive for motorbuses; and the automotive engineer has responded in a splendid spirit of co-operation in adapting the motorbus to meet the new conditions.

Aside from the considerations already named that tend toward the use of the electric drive in combination with the internal-combustion engine for propelling motorbuses, an examination of patent-office records and automotive publications covering a period of more than 30 years shows the sustained activity and endeavor made in this field, and indicates that simplicity, continuous torque, ease of control and durability have been appreciated from the earliest days of the industry. No attempt will be made to enumerate or to discuss the many efforts of inventors and engineers to embody the electrical idea in and adapt it to the automobile. A study of the early attempts, however, is most interesting and profitable. The fact that the basic idea of the electric drive has persisted throughout all these years, in spite of the many failures and discouragements common to the early days of any new art, is evidence that the practice of shifting gears with several reductions, in combination with a clutch for disconnecting the internal-combustion engine, has not measured up to the highest ideals; the use of electricity, therefore, has been invoked to supply a transmitting device better adapted to utilizing the characteristics of the gasoline engine and to allowing full use of the advantages of this modern prime-mover.

Early Fifth Avenue Buses

The first important use in this country of the electric drive for motorbuses was in 1904 when an experimental single-deck motorbus, shown in Fig. 1, was designed and built by the General Electric Co. for the New York Transportation Co. for use on Fifth Avenue, New York City. This served to work out many interesting details, both mechanical and electrical, including electric starting, and led to the construction of 10 electric-driven motorbuses by the same company in 1907. These were placed in operation in 1908 and continued on that route for 6 years, together with similar double-deck DeDion-Bouton buses having mechanical drive. The chassis of these buses is illustrated in Fig. 2. The fact that electric-driven motorbuses remained in service on the principal avenue of the largest

TABLE I

DATA ON EARLY FIFTH AVENUE MOTORBUSES

Data	General Electric Electric-driven Bus, Double-motor	DeDion-Bouton Mechanically-driven Bus	General Electric Electric-driven Bus, Double-motor	General Electric Electric-driven Bus, Single-motor
Date of First Run	Sept. 14, 1905	September, 1906	May 15, 1908	September, 1910
Number of Motorbuses	1	1	10	1
Type of Body	Single-Deck	Double-Deck	Double-Deck	Double-Deck
Number of Passengers	30	16 inside, 18 outside	16 inside, 18 outside	16 inside, 18 outside
Weight of Chassis, lb.	10,000	5620	5967	5550
Weight of Motorbus, lb.	15,500	9070	9417	9000
Weight of Motorbus, Loaded, lb.	20,000	14,170	14,517	13,500
Engine, Type	Gas Engine & Power Co., Four-Cylinder, 6x6-in.	DeDion, Four-Cylinder, 4.2x5.2-in.	DeDion, Four-Cylinder, 4.2x5.2-in.	DeDion, Four-Cylinder, 4.2x5.2-in.
Electric Generator	TD, Six-pole, 110-volt, 55-amp., 600-r.p.m.	Gear Box and Clutch	TD, Six-pole, 125-volt, 60-amp., 900-r.p.m.	TD, Six-pole, 125-volt, 60-amp., 900-r.p.m.
Electric Motors	2 GE-1012, 85-volt, 40-amp., 1200-r.p.m.	Gear Box and Clutch	2 GE-1026 125-volt, 30-amp., 1600-r.p.m.	1 GE-1027, 125-volt, 60-amp., 1300-r.p.m.
Control	Foot Accelerator Electric Reverse	Foot Accelerator Clutch and Gear-Shift	Foot Accelerator Electric Reverse	Foot Accelerator Electric Reverse
Free-Running Speed on Level, m.p.h.	15	20	18	19
Gearing	Spur and Chain, 16 to 1	Bevel and Internal-Spur, 9 to 1	Herringbone and Chain, 14.5 to 1	Bevel and Internal-Spur, 9 to 1
Driving Wheels	36-in. Diameter, Solid	38-in. Diameter, Solid	40-in. Diameter, Solid	38-in. Diameter, Solid
Aver. Fuel Consumption, miles per gal.	1.7	4.0	3.3	3.5
Acceleration, m.p.h. per sec.	. . .	1.25 to 11 m.p.h.	1.25 to 11 m.p.h.	1.25 to 11 m.p.h.
Weight of Gear Box, lb.	. . .	600	. . .	. . . .
Weight of Electrical Equipment, lb.	1940	. . .	1310	1170

city of this country indicates that they must have operated on schedule and with a reasonable degree of efficiency.

All were equipped with the double-motor electric drive, one being changed in 1911 to the single-motor drive. The principal difficulty with these machines was that the engines, which were of special design, had not been sufficiently developed, and they were later replaced with DeDion-Bouton engines.

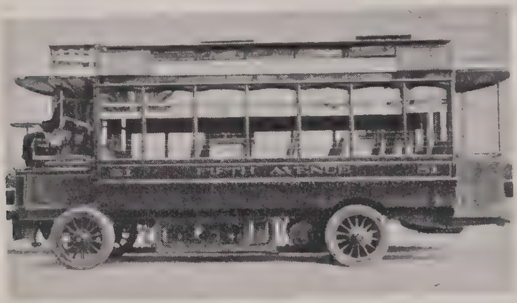

Fig. 1. Experimental Single-deck Motorbus Built in 1904

The equipment included electric starting. The construction of ten electric-driven motorbuses followed in 1907.

The first double-deck DeDion-Bouton motorbus was placed on Fifth Avenue late in 1906, being followed by 16 of the same make in 1907. The 10 electric-driven motorbuses referred to having been placed in commission in 1908, the question arose early in 1909, as to what type of transmission should be used in 25 additional motorbuses that were about to be ordered. The president of the operating company stated at that time that the electric transmission feature was a complete success and that if the results of the test of the single-motor bus had been known, the order would not have been placed abroad for mechanically-driven buses. Furthermore, electric-driven chassis were not in regular manufacture and, consequently, were not available in time to meet the demands of the New York Transportation Co. These points are mentioned in answer to the question why so promising an undertaking was seemingly abandoned.

From an electrical standpoint, these motorbuses demonstrated the practicability of the electric drive for their propulsion and may also be considered as the first considerable group of motorbuses of any kind designed and built in the United States and used in regular service.⁽¹⁾ The wiring diagram of these buses is reproduced in Fig. 3.

After this early start came a period of comparative quiet in the motorbus business, followed by the so-called "jitney bus," which was usually mounted on a standard chassis, carried only a small number of passengers and, for the most part, was operated by an individual or small owner independently of the public utility companies. The jitney-bus era continued for years, but jitney buses were found to be an unsatisfactory attempt to solve the transportation problem for cities and suburbs owing to the lack of reliability of the service. These buses, moreover, did not prove financially successful for they had not been specially designed and built to meet the severe demands of public service.

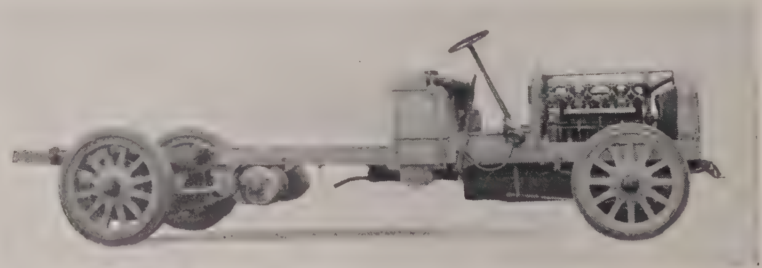

Fig. 2. Double-motor Motorbus Chassis

Buses thus equipped were placed in operation in 1908 and continued on the Fifth Avenue route for 6 years.

About the time that the electric drive was being tried out in motorbus service, it was also successfully employed for railroad passenger-cars, and later, with the Diesel engine, for ship propulsion. The most recent development is in connection with oil engines for locomotives. In each case, the electric drive has served to smooth out the irregular impulses of the internal-combustion engine.

---

(1) See *Street Railway Journal*, Dec. 2, 1905, p. 986; GENERAL ELECTRIC REVIEW, November, 1908, p. 214, and March, 1912, p. 130.

Electric Drive in England

The idea of the electric drive has found practical expression in England where the Tilling-Stevens Motors, Ltd., of Maidstone, began experimental work on them in 1907, and from 1911 to the present time has built and put into service more than 1300 electric-driven motorbuses. Of this number, some 460 are operated by the London General Omnibus Co. and the Thomas Tilling, Ltd., for motorbus service in London. Fig. 4 shows a single-deck vehicle. The electric-driven buses have about the same fuel consumption as the standard London General Omnibus Co.'s vehicles, the maintenance charge, however, being from 10 to 15 per cent less.

The Tilling-Stevens system consists of a shunt-wound interpole generator, having variable fields connected through a controller and resistance-box to a series-wound interpole motor, the fields of which are designed for shunted operation as shown in the diagram reproduced in Fig. 5. The controller has forward, neutral and reverse points, while the resistance-box, which is operated by a separate lever, has a series of points so that the generator fields can be weakened as the motor fields are strengthened and vice versa. The highest speed is obtained when the motor fields are weakened. In a modified form of this system, a compound-wound generator is used, the series field being varied by the resistance-box, which is used to shunt the motor field.

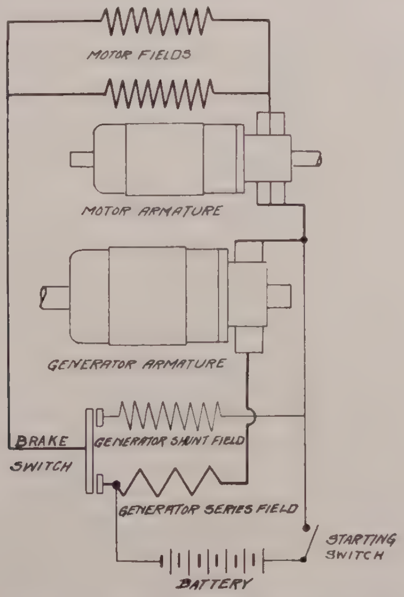

Fig. 3. Wiring Diagram of Single-motor Chassis

Buses of this type were the first of any kind to be designed and operated in quantity in the United States.

According to the writer's observation, the performance of the Tilling-Stevens motorbuses in London has been very gratifying, owing to the smooth acceleration and quiet running because of the inherent characteristics of the electric drive. Although the electric motor and control elements of the 10 Fifth Avenue motorbuses referred to met the requirements of service as it existed at that time, the characteristics of the generator were such that when the throttle was suddenly opened the engine was not instantly loaded and, therefore, raced until the voltage was built up to the value necessary to start the motorbus. This resulted in an appreciable lag between the time of opening the throttle and the movement of the motorbus that not only interfered with the acceleration and the schedule, but caused a somewhat higher fuel-consumption. Furthermore, the generator characteristic, as can be seen from Fig. 6, was comparatively flat, so that in ascending grades with their increased current demands, high voltage meanwhile being maintained, the engine was overloaded and operated at a low point on the brake-horsepower curve.

Fig. 4. Tilling-Stevens Single-deck Electric-driven Vehicle

Of the 1300 electric-driven motorbuses built by this Company, 460 are operated in London by the London General Omnibus Company and the Thomas Tilling Limited.

Modified Form of Drive with Storage Battery

Although this article deals primarily with a form of electric drive in which all the electric energy generated passes directly through the driving motors, a modification of this system has been devised by Prof. Morton Arendt, of Columbia University. This includes a storage-battery of sufficient size to absorb a part of the output of the generator as required and to deliver this energy to the motors for accelerating and hill-climbing. A motorbus embodying this system has been tested recently in New York City and represents a different solution of the problem. The chassis, as can be seen from the side view reproduced in Fig. 7, is of the conventional motorbus type, adapted to carry a 25-passenger single-deck front-entrance body. The prime-mover is a four-cylinder 3⅝ x 5⅛-in. gasoline engine, and is much smaller than that ordinarily used for a motorbus of this capacity when equipped with mechanical drive. The engine is direct-connected to a compound-wound generator and supplies electrical energy to the driving motors and battery in varying degree, depending upon the traction requirements. A system of cut-outs and relays is provided for controlling the battery, which may either charge or discharge to meet the power demand. An automatic controlling device is provided to reduce the engine speed to about 900 r.p.m. when the vehicle is coasting or standing still. By the use of an engine of small dimensions and power, operating most of the time on full open throttle, high fuel economy is obtained. A double worm-driven rear axle is used, which is shown in Fig. 8. The battery weighs 650 lb. and, under normal road conditions, is kept fully charged by the engine-generator set. The motorbus has a free-running speed on the level of from 30 to 35 m.p.h. and has the advantages common to the electric drive. Its weight with electrical equipment is 10,200 lb.

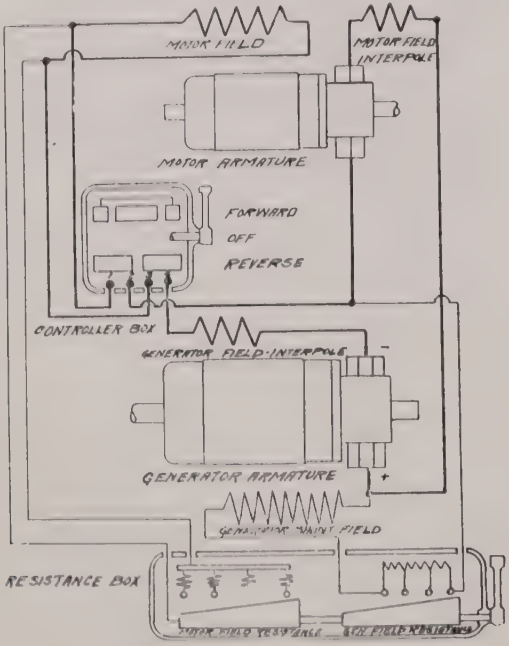

Fig. 5. Wiring Diagram of Tilling-Stevens Motorbus

A shunt-wound interpole generator having variable fields is connected through a controller and resistance box to a series-wound interpole motor, the fields of which are designed for shunt operation.

Development of Electric Power Plants

The period of 15 years following the installation of the 10 electric-driven buses on Fifth Avenue was not one of idleness from an electrical standpoint. Although the motorbus situation itself was comparatively quiet, research and experimental work were carried on without interruption and each year a number of electric-driven equipments were built for motor vehicles of various kinds. These included vehicles of special design for municipal work and street cleaning, tractors for refuse collection, fire apparatus and trucks and armored tanks and gun-mounts for the United States Army during the war.

Many methods of mounting and driving the generators and many forms of control and generator characteristics were tried in these developments but, in the main, the generators were compound-wound and self-excited with a comparatively flat voltage curve. The operation of the vehicles was uniformly successful, since acceleration, maintained speed on grades and fuel consumption were not considered so important then as they are now.

Although only a few important motorbus lines existed from 1908 to 1923, it was appreciated by electric-traction engineers that, in time, an opportunity for the electric drive, in conjunction with the internal-combustion engine, would present itself. For this reason the problem was carefully studied and experiments made, using a compound-wound generator with differential series field instead of a cumulative field, the shunt field being separately excited by a small shunt-wound generator that formed a part of the main unit. A battery-excited teaser winding (see Fig. 9) was also employed for the exciter field. This arrangement gave very satisfactory

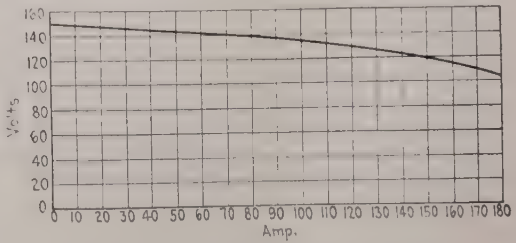

Fig. 6. Characteristic Curve of Generator Used on Second and Third Electric-drive Fifth Avenue Motorbuses, 1908 and 1910

results. Racing of the engine when starting, as previously referred to, was corrected, and improvement was obtained in acceleration, speed on hills, and fuel consumption.

With separate excitation of the shunt field, it is possible to obtain a drooping voltage-characteristic that allows the engine to operate at higher speeds during the acceleration cycle and on grades when heavy currents are required, the output being kept within the power limitations of the engine because of the nearly constant output that is maintained with open throttle. In other words, at the time of starting, when high torque is necessary, the current is high and the voltage low, a condition that changes gradually and automatically with the increase of speed of the motorbus, until the current reaches the rate required for normal running, when the voltage is correspondingly higher.

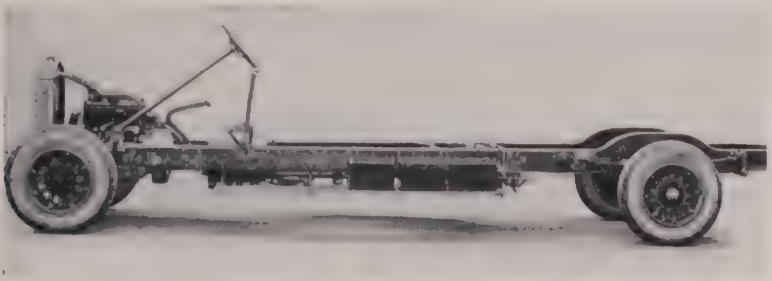

Fig. 7. Arendt Electric-drive System Using Storage Battery

High fuel economy results from the use of a small, low-powered engine operating mainly on wide open throttle.

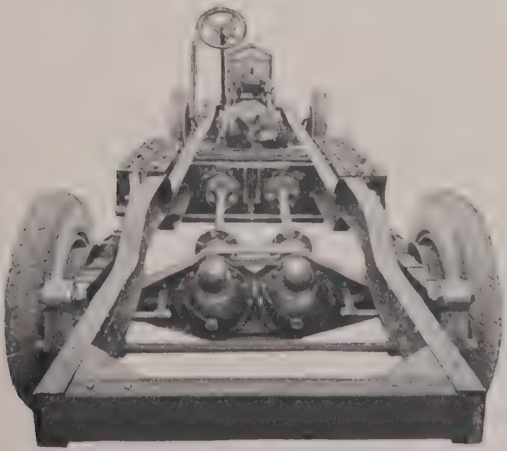

Fig. 8. Worm-driven Rear Axle on the Arendt Chassis

This motorbus has the advantages of the electric drive system and develops a free running speed of 30 to 35 miles an hour on level road. The complete chassis weight is 10,200 lb.

Reference to the curve reproduced in Fig. 10 will show that the kilowatt output of the generator is substantially constant throughout the cycle of operation. It is needless to say that, aside from this major change, which was brought about by motorbus demands, many minor changes were made both in the electrical and the mechanical details of the generator, motor and controller that tend toward higher efficiency and greater output for a given amount of material.

The question of frame construction, self-ventilation, details of mounting and the like received attention, and improvement was made along all these lines. Experience gained from the long-continued use of electric motors in street-railway-car propulsion and for storage-battery trucks indicated the great durability and reliability of this form of transmission. It is not unusual to find electric motors that have been in continuous traction service for 20 years or more. In working out the electric drive, advantage has been taken of the many improvements in electric motors that have been brought about by modern manufacturing methods, created by the almost universal employment of this device for industrial purposes.

Electric-drive Vehicles at Philadelphia

An opportunity to utilize the experience acquired came in July, 1923. Shortly before that time the Mitten Traylor Co. had designed and built a number of 64-passenger double-deck mechanically-driven motorbuses intended for the use of the Philadelphia Rural Transit Co. on boulevards and as feeders to its main lines. One of these motorbuses is shown in Fig. 11. J. A. Queeney, vice-president of the Company, desired to utilize the advantages of the electric drive and control, and his demand for the necessary equipment resulted in the design of a special generator and motor embodying all that had been learned in the art during the transition period.

It was decided to rebuild one of the Philadelphia Rural Transit chassis, substituting the electric for the mechanical drive. This would allow a direct comparison to be made quickly under identical conditions of operation. The work of rebuilding the chassis was carried out by the J. G. Brill Co. and the General Electric Co. jointly, and motorbus No. 102 with electric drive was run in Philadelphia for the first time on June 13, 1924.

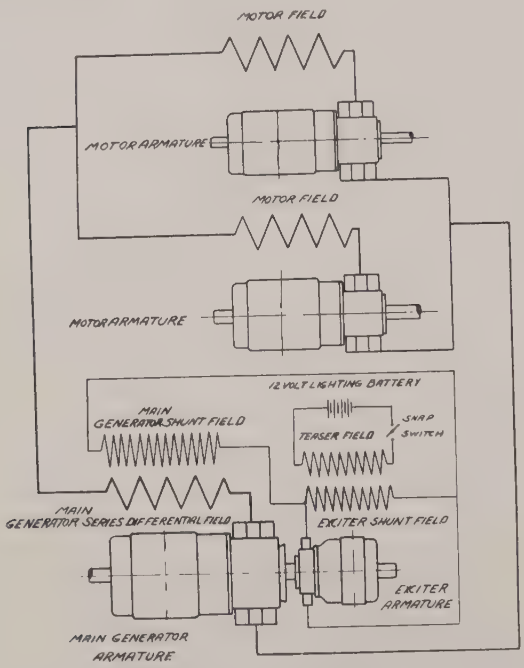

Fig. 9. Wiring Diagram of General Electric System of Electric Drive for Motorbuses

The generator is compound, with a series winding, connected differentially. The shunt wound exciter prevents racing the engine and improves the acceleration and fuel economy.

The capacity of the generator and of the motors was based upon the operating requirements and traction data submitted. These units were designed to utilize the output of the six-cylinder 4 by 6-in. gasoline engine with which the chassis was equipped. A view of the power-plant is given in Fig. 12. The generator embodied a compound winding with differential series winding and a separate exciter for the shunt field.

The motors were series wound, with a torque characteristic of about 4 to 1. The latest practice in the electrical design and manufacture of generators and motors was used throughout. The mechanical design included cylindrical magnet-frames composed of steel castings with aluminum-alloy heads. The exciter formed an integral part of the main generator casting, insuring a compact and strong unit. All fields were of the four-pole type, without interpoles.

As will be seen, the armatures of the generator and of the exciter were mounted directly on a hollow shaft, carried by large ball-bearings mounted in the heads. Self-ventilation by radial fans was provided on all the units to obtain the greatest possible output per pound of material. Brackets for mounting the generator were provided on the front heads, the exciter-head being made cylindrical to fit a special cross-member of the frame. The armature was driven by a propeller-shaft passing through a quill with a flange coupling at the rear end and an internal gear-coupling attached to the flywheel at the front.

The object of this construction was to give, in effect, a long couple, relieving stresses on the crankshaft, and also to allow for a small amount of misalignment. Experience had shown that the rear bearings of some automotive engines were not of sufficient size to carry the added weight of the armature. This arrangement has proved successful in operation. Certain engines, however, have large crankshafts with rear bearings of ample size that allow the head of the generator to be bolted directly to the bell-housing of the engine, the generator shaft being attached to the crankshaft by bolted flanges. When this construction is used it is possible to omit the

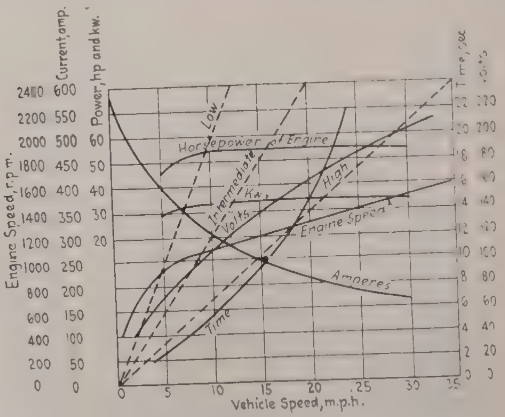

Fig. 10. Acceleration Curves of 64-passenger Electric-driven Motorbus No. 102

The kilowatt output of the generator is substantially constant throughout the cycle of operation.

front generator bearing. Various forms of coupling have been tried with the flexible-shaft design, and the best results so far have been obtained with the rubber buffer type, in which the turning effort of the crankshaft is communicated to the armature quill through compressed rubber balls. The field coils are asphaltum-treated and are thoroughly protected from moisture and wear. The brush rigging and brushes are of the automotive type and are accessible. The motors are self-ventilated, having the same general electrical and mechanical features as the generator.

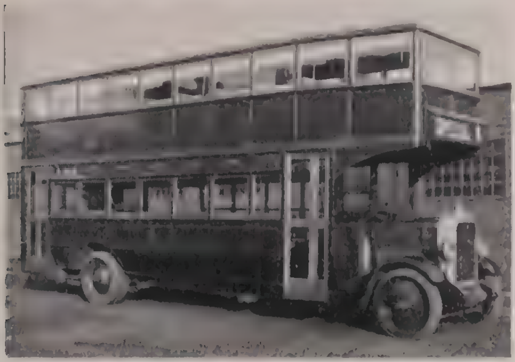

Fig. 11. Double-deck 64-passenger Mechanically-driven Motorbus Designed for Philadelphia Rural Transit Co.

This was rebuilt by substituting electric for mechanical drive.

Double motor drive was specified by the Philadelphia Rural Transit Co. for Motorbus No. 102. This motor is mounted directly on the heads, the magnet frame is cylindrical throughout and the windings are self-ventilated. The arrangement of the motors is shown in Fig. 13. Single-motor driving equipment of the same general mechanical and electrical characteristics is also available. The weight of the generator is 900 lb. and of the motors in the double-motor drive 445 lb. each, the single motor weighing 750 lbs.

For normal operation in city traffic where no steep grades are encountered, the control is by foot-accelerator, which acts upon the throttle. Under these conditions the control is simple and automatic. As it is necessary, however, to reverse the motorbus at times and to provide for grades and electric braking, a controller is required. This is a simple device, with the latest forms of fingers and drum, and is operated by a lever near the driver's seat.

Fig. 14 shows a form of this controller, and the connection diagram, Fig. 15, gives an idea of the combinations that can be obtained with single- and double-motor equipments. The series connection has been added to give higher tractive effort on steep grades. Moderate grades can be negotiated with the controller in the parallel position. The electric drive also allows braking by the controller. This originally was intended only to relieve the brake-linings and drums of undue wear when descending long and steep hills, but it has been found to be an effective form of emergency brake. The operation of the brake is shown in the diagram at the right of Fig. 15, and amounts to placing the motors in the reverse position in the circuit with the generator and resistance in series. Until the engine speed has been increased, it is, therefore, regenerative; thereafter, the action tends to reverse the motors. Various arrangements as to the location and the operation of the control have been tried, but these are a detail that depends somewhat on the design of the chassis.

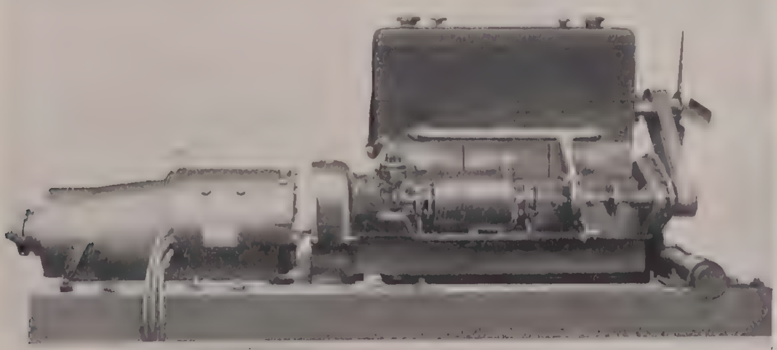

Fig. 12. General View of Power Plant of Motorbus No. 102

Motor and generator capacity were designed to utilize the output of the 6-cylinder 4 by 6-in. gasoline engine.

The wiring of the electric-driven equipment is comparatively simple, fuses of high ampere capacity being placed in the motor circuits. These fuses protect the electrical equipment from continuous overload and provide means for opening the motor circuit on the road, if desired. In the case of the double-motor drive, one motor can be cut out by removing the fuse.

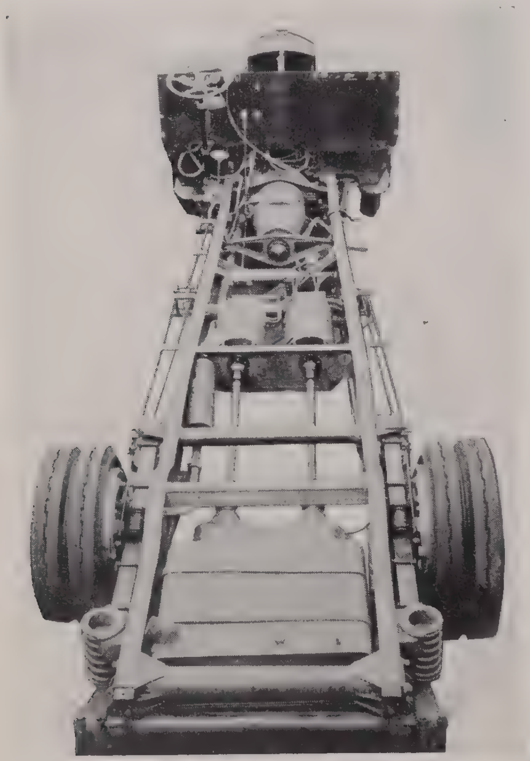

Fig. 13. Chassis of Philadelphia Rural Transit Company's Bus No. 102, Showing Arrangement of Generator and Motors

The weight of the generator is 900 lbs. and of the motor 445 lbs. each.

Single Versus Double Motor Drive

Fig. 13 shows the design of the chassis of motorbus No. 102, as built for the Philadelphia Rural Transit Co. It will be noted that this motorbus has the double-motor drive, which brings up the subject of single versus double motors for propulsion. Each, undoubtedly, has its good features. The single motor is lighter for a given chassis, is mounted more easily in the frame, can be employed with the standard rear-axle and differential, and involves less expense than the double-motor equipment. These seemingly important advantages are offset in the opinion of many engineers and operating men, by the advantages of the double-motor drive in reducing the diameter of the driving motors, in allowing a lower platform and in the ability of the two-motor drive with the motors in parallel to move the driving-wheels, somewhat as if a locked differential were used. Such a rear axle is shown in Fig. 16.

Motorbuses, particularly in city traffic, must run close to the curb to accommodate passengers; and at such times it has been found that the inner and outer driving-wheels do not always have the same road conditions, so that one may be held and the other may spin without moving the motorbus. This difficulty does not occur with the double-motor drive. It has also been found that the double-motor drive reduces the skidding effect under slippery conditions; and this in itself is an important factor in the safe transportation of passengers in thickly congested traffic.

With the electric drive, it is possible to use higher ratios of reduction in the rear axle than with the mechanical drive, for the armatures of the motors can be run independently of the engine speed. The ratios commonly used vary from 9 to 1 to 13 to 1, the former being used in suburban and the latter in city work and in heavy traffic. The armatures are designed to operate safely at the rotative speeds caused by the high ratios of reduction.

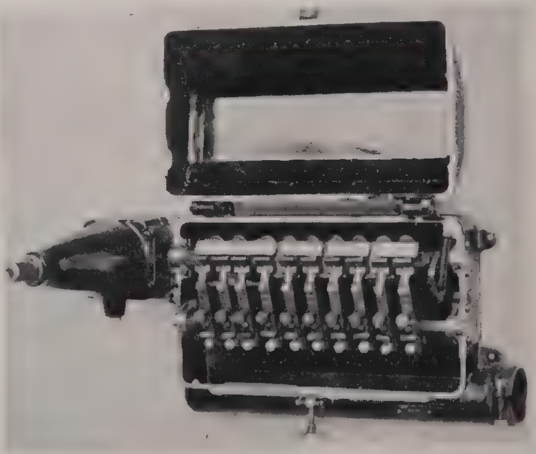

Fig. 14. Controller Used in Motorbus No. 102

Equipped with the latest forms of fingers and drum and operated by a lever from the driver's seat.

Engines

During the last few years, the tendency has been to increase the power of motorbus engines of both the four- and the six-cylinder types, the latter being used in a number of instances. This increase of power applies to both mechanically- and electrically-driven buses and represents an advance in the art. When four- or six-cylinder engines are used, it is desirable to have a certain amount of excess power, regardless of the type of drive. It is generally considered that the overall efficiency of the electric is lower than that of the mechanical drive, but this difference is more than offset by the fact that the engine of an electrically-driven motorbus can be operated at all times at the most efficient point on the brake-horsepower curve, a thing that cannot be done with the mechanical drive because it has a fixed ratio of reduction.

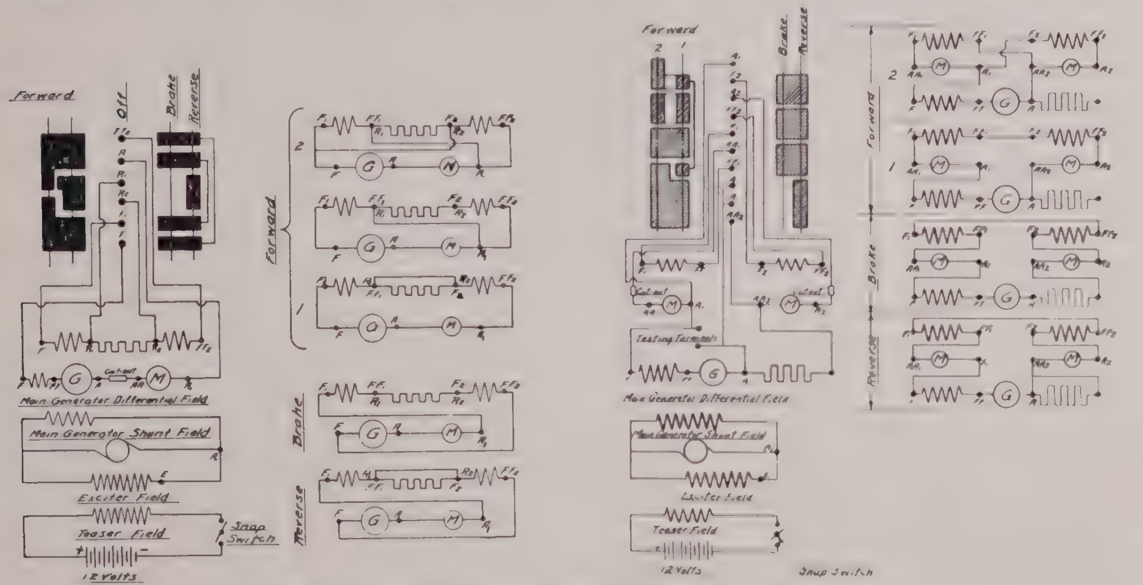

Fig. 15. Single- and Double-motor Connections of Controller

Left: Single motor. Right: Double motor. Right-hand view also shows the connections for electric braking.

Fig. 16. Rear Axle Arranged for Double-motor Drive

The advantages of this drive are the smaller diameter of the driving motors, lower platform and the ability of the two-motor drive, with motors in parallel, to move the driving wheels independently.

Generator and Motor Mounting

The mounting of the generator and the motors, in the many cases that have been worked out, has been found to be comparatively simple, requiring little alteration of the standard motorbus chassis.

Reference to Table 1 shows that the weight of the double-motor bus was only 347 lb. in excess of the standard DeDion bus with mechanical drive; whereas, the single-motor bus actually weighed less than the DeDion-Bouton. This comparatively small difference was partly due to the special design of the electric-driven chassis, as the weight of these chassis actually increased 710 and 570 lb. respectively because of the use of electrical equipment.

From the experience with the various electric-drive problems so far encountered, it appears that the speed and load obtaining in motorbuses of today require a somewhat definite amount of weight in the chassis for strength, regardless of the form of drive used. It is the opinion of the writer, however, that with the electric drive the weight of the frame and the chassis can be reduced owing to the continuous effort of the electric motor. This can be illustrated in a simple way by an hydraulic analogy, Fig. 17. Here the two explosions per revolution of a four-cylinder gasoline engine are compared with the many impulses of the electric motor. In one case, the turning-effort is highly intermittent; in the other, it is almost continuous, being represented by sine curves. The impeller wheels and nozzles illustrate the comparison.

Weight is governed largely by what it is desired to accomplish and cannot be considered in the abstract. The weight of motorbus No. 102 with electric drive, for example, is 213 lb. per passenger, whereas the weight of a steel Pullman sleeper is nearly 5000 lb. per passenger. A comparison of the costs per passenger in these cases shows $172 in the former, as against $1333 in the latter. The weight and cost of vehicles must clearly be measured by the requirements of the problem and from the standpoint of the return on the investment. These points should be kept in mind when comparing transmissions of various kinds.

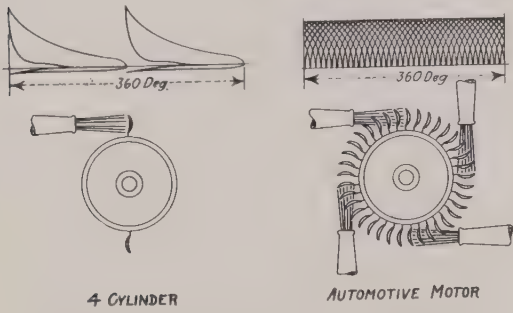

Fig. 17. Hydraulic Analogy of the Turning Efforts of Four-cylinder Gasoline Engine and Four-pole Electric Motor

In one case the turning effort is intermittent; in the other, practically continuous.

Performance Data of Philadelphia Motorbuses

The performance of the electric-driven motorbus No. 102 in Philadelphia in the last 11 months has from the beginning attracted the attention of automotive engineers and motorbus builders. Already a number of the latter have installed electric-driven equipment in their standard chassis for experimental purposes, and others are preparing to do so. Several motorbuses have already been completed and tested on the road, and the results so far obtained have not only been encouraging, but have led to the placing of definite orders for electric-driven equipment by a number of public utility companies. As these events are so recent, the only extended service report that can be made at this time must relate to the Mitten Management Motorbus No. 102. An initial order for 215 of these motorbuses was placed by the Mitten Management early in November, 1924, and form part of a plan involving a total of 700.

The standard Philadelphia Rural Transit chassis, complete with a 65-passenger double-deck body, weighs 15,036 lb., while motorbus No. 102, which is identical with it except for the substitution of the electrical for the mechanical drive, weighs 16,760 lb., an increase of 1724 lb. No attempt was made to modify the chassis except to change from the gearbox to the generator and the motors. The engines of these motorbuses were found by dynamometer test to be identical in output.

Attention is called to the acceleration curve shown in Fig. 10, which was prepared from road tests made on Aug. 13, 1924. Sixteen acceleration tests of motorbuses Nos. 102 and 103 were run side by side over the same course and under the same conditions, except that a more skilful driver operated the mechanically-driven motorbus. These tests showed that motorbus No. 102 led motorbus No. 103 nine times by from one-quarter to one-half a bus-length, on four runs the two machines showed equal acceleration, and on three runs the mechanically-driven bus led slightly.

A service test was made over a regular course of 4.2 miles, each motorbus operating under like conditions, with the results given in Table 2. All stops were of 10-sec. duration.

Fuel tests were then run and indicated a mileage for motorbus No. 102 of 4.7 miles per gal. as against 3.9 miles per gal. for the mechanically-driven motorbus, the latter being an average based upon several months' operation. Motorbus No. 102, over a period of 11 months, part of the time on a regular schedule of 190 miles per day, has shown a fuel consumption of about 4 miles per gal. in each case.

Fig. 18. One of the 215 Double-deck Electric-drive Yellow Coach Motorbuses Built for the Philadelphia Rural Transit Co.

These buses have a higher free-running speed than the No. 102 motorbus, being equipped with larger engines.

Comparative engine-revolution tests were made over the route, 4.2 miles, on a 12-stop schedule, a counter being attached to each crankshaft. This showed 19,906 engine revolutions for the mechanical drive and 17,201 for the electrical, a difference of 2705 revolutions in favor of the electrical. The same test was repeated with 36 stops, the engine revolutions being 25,664 and 21,240, respectively, a difference of 4424 revolutions in favor of the electric drive.

TABLE II

MOTORBUS SERVICE TESTS

Number of Stops	TIME OF TRIP, MIN. SEC.	
	Mechanical Drive	Electric Drive
13	15—29	14—28
19	17—48	16—46
38	25—31	23—43

The results so far discussed refer to equipment designed to operate at comparatively low engine speeds. From the standpoint of acceleration and motorbus performance, however, a higher engine-speed will give better results, but at the cost of greater wear and tear on the engine and increased fuel-consumption. But it is expected in either case that the constant-output operation of the engine with electric drive will show greater life and less maintenance of the engine and the chassis.

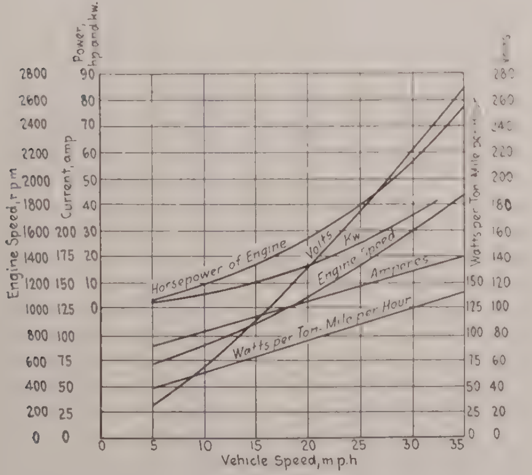

Fig. 19. Sustained Speed Curves of Yellow Coach Electric Drive Motorbus No. 985.

Wheel diameter 34 in. Ratio of reduction 11:1. Total weight as tested: 18,800 lb.

The order for 215 electric-driven motorbuses placed with the Yellow Coach Mfg. Co., of Chicago, covered both double- and single-deck motorbuses. One of the double-deck type is shown in Fig. 18. The first chassis was completed in February of the present year. After a period of running-in, a series of road-tests was made, the results of which are shown in the curves reproduced in Figs. 19 and 20. These are similar to those of the Philadelphia test, but have a higher free-running speed, owing to the use of the larger engine shown in Fig. 21. The test load was 1000 lb. greater than in the case of the original Philadelphia Rural Transit chassis No. 102.

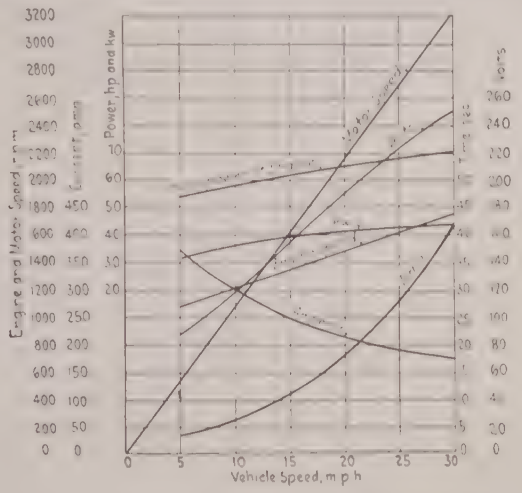

Fig. 20. Acceleration Curves of Yellow Coach Electric Drive Motorbus No. 985

Conditions of load and test the same as for Fig. 19.

Other Applications of the Electric Drive

Early in March of this year the Fageol Motors Co., of Oakland, Cal., and Kent, Ohio, completed a single-deck motorbus of the type illustrated in Fig. 22, equipped with the same electric drive and having an overall weight of 14,280 lb. This was given a trial road-run over the Lincoln Highway from Kent, Ohio, to Pittsburgh, Philadelphia, New York City and Albany, N. Y., a distance of 650 miles. This motorbus reached its destination on March 3; since that time it has been used by the Capitol District Transportation Co. on routes in that city. The cross-country run referred to included heavy grade climbing over the Allegheny and Blue Ridge Mountains, grades 10 miles in length and averaging 12 per cent being negotiated without difficulty. The electric brake was used successfully in descending. On the level the maximum road speed was 40 m.p.h. The total running time for the entire trip from Kent, Ohio, to Albany, N. Y., was 35 hr. 20 min., an average speed of 18.5 m.p.h. Although this is considered only a short run, the fuel consumption was 4 miles per gal. No additional engine oil was required.

In Albany, the Fageol motorbus, having a total weight of 18,000 lb., was tested successfully over grades of 9.8 per cent, at a speed of 9 m.p.h. The Fageol Motors Co. is now building 34 electric-driven buses, 19 being for the Capitol District Transportation Co., of Albany, N. Y., and 15 for the Georgia Railway Light & Power Co., of Atlanta, Ga.

A single-deck electric-driven Yellow Coach motorbus was recently run from Albany, N. Y., to Boston, and was demonstrated in a number of cities in eastern Massachusetts, Rhode Island and Connecticut, before making the run to Philadelphia. It aroused much interest and enthusiasm among public utility men wherever it was shown. This test has just been completed and data are not yet available.

Advantages of the Electric Drive

The survival of the electric drive depends, like all other things, upon its fitness for the purposes intended. To exist, it must demonstrate its superiority over the mechanical drive under service conditions.

A study of the test and operating records of the many electric-driven road vehicles built prior to 1924 shows that these were not equal to similar vehicles equipped with mechanical drive in the matter of acceleration, speed on grades and fuel economy. They did, however, possess many other advantages that have been found to exist in electric-driven motorbuses, such as freedom from shock in starting and stopping, simplicity of control and durability of electrical equipment. Furthermore, it was reported that the engines of the electric-driven Fifth Avenue motorbuses could be run for a much longer period without overhauling than could engines of the same type in motorbuses equipped with mechanical drive. The electric-driven system not only retains all the good features of the early electric drives but, at the same time, presents a number of advantages that are particularly important when considered in connection with modern transportation demands and increasing traffic congestion.

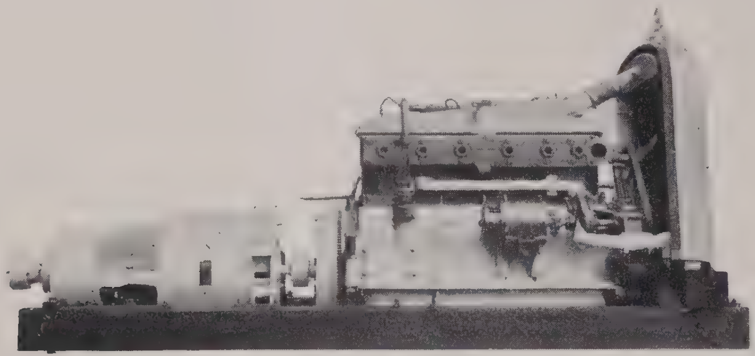

Fig. 21. Automotive Generator with Exciter Direct-connected to Gasoline Engine

The generator is rated at 125 volts, 200 amp., at 1200 r.p.m. The engine is the 6-cylinder, 4¼ by 5½ in., model YZ sleeve valve type.

The principal criticisms that have been raised against the electric drive by those who have not had an opportunity to study the actual operation of the system are the increase in weight and cost, and the lower overall efficiency of transmission on direct drive. Although all these are true and, in the abstract, appear to be important factors, they are outweighed by the other considerations that already have been demonstrated.

It has been maintained that the mechanical transmission in high gear with the direct drive is much more efficient than with the electric drive, but experience has shown that, in city traffic with a heavy schedule, it is not so much a question of efficiency in free running as in starting and acceleration. Here the electric drive has the advantage even with somewhat greater weight. In a comparison made in Philadelphia during the last 12 months between motorbus No. 102 with the electric drive, and motorbus No. 103 with mechanical drive, it was found that the electric-driven motorbus could cover the route in 20 per cent less time. This was due to the smooth and continuous acceleration characteristic of the electric drive, which is inherent, automatic and independent of the will of the driver, who simply opens the throttle fully by depressing the accelerator. Skill and experience on the part of the operator are important factors when it is necessary to operate a clutch and change the gears. Another advantage of the electric drive is the fact that it is impossible for the operator to race or to stall the engine, so long as it is in operating condition and fuel is provided. This is governed by the drooping characteristic of the generator.

Tests so far indicate that, in the matter of fuel consumption, little difference exists in the bus-miles per gallon. The limited engine-speed common to the electric drive should, in the long run, show a lower gasoline and lubricating-oil consumption. With the smooth operation and quiet running of the electric-driven motorbus, because of the continuous torque feature of the motors and the generator, every reason exists for believing that the cost of maintenance will be considerably lower than that of a mechanical drive.

Other advantages of the electric drive are freedom from clutch and gear-shifting, which momentarily distract the attention of the driver when running in heavy traffic. It is a matter of easy computation to show that, in a day's run of 180 miles, the driver of a motorbus equipped with mechanical transmission is called upon to make several thousand gear-shifts, which are not only fatiguing, but reduce his efficiency and alertness and tend to increase the running-time of the motorbus. With the electric drive, the only lever used for normal operation is the foot accelerator, operating on the throttle of the engine. All these are vital points from the standpoint of safety of operation. The objection of higher cost, which is sometimes raised, is more than offset by the ability of the electric-driven motorbus to cover a given schedule more quickly than can be done with the mechanically-driven motorbus when operated by an average driver. As in all commercial problems, it is the question of interest on the investment, not of first cost, that counts, so that, if the electric-driven motorbus can cover a given schedule in shorter time with greater comfort and safety to passengers, making it a more desirable means of transportation, it is clear that a motorbus with this form of transmission will cover more miles per day per dollar invested. It is simply a question of giving the kind of service that is demanded by the public, not one of weight, cost, or overall efficiency of the drive in high gear. It is safe to predict that the use of electricity in conjunction with the internal-combustion engine will henceforth play an important part in the propulsion of motorbuses.

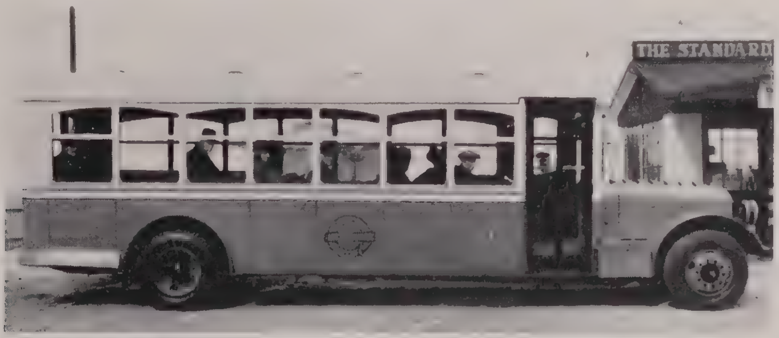

Fig. 22. Fageol Single-deck, Double-motor Electric-drive Motorbus

This motorbus has an overall weight of 14,280 lbs.

Study of Time Lag of the Needle Gap

By K. B. McEachron and E. J. Wade

Lightning Arrester Engineering Department, General Electric Company

In these days of radio we have learned to talk fluently of frequencies in the millions of cycles per second, but we have by no means as clear a conception of the enormous magnitude of their rates of change. To a Frenchman, M. Dufour, belongs the credit of devising an oscillograph which is actually capable of recording in photographic form electric oscillations having frequencies of 200,000,000 or more cycles per second. That the Dufour oscillograph is an instrument of extraordinary value is brought out by the work done with it by the authors of the present article, in their researches on the time lag characteristics of the needle gap. This work is of particular importance in that it provides the lightning arrester engineer with a powerful new aid in the study of insulation behavior under the conditions imposed by transient phenomena. This article was given as a paper before the annual convention of the American Institute of Electrical Engineers, in June of this year. We call attention to it not only because it is an interesting example of what science can do in the realm of infinitesimal dimensions, but especially because with it the authors have made a very significant contribution to the important subject of transmission line protection.—Editor.

The Study of Transients

One of the most difficult and perhaps also one of the most fascinating problems which the electrical engineer of today is called upon to study is that of the transient phenomena occurring in electrical circuits. Failure of apparatus, caused by the puncture or flashover of insulation due to overvoltages, the duration of which may be of the order of a few micro-seconds, has made desirable the use of lightning arresters which limit the voltage to safe values. Since in practice many of the steep front traveling waves are the result of the sudden releasing of a bound electrostatic charge, lightning arrester laboratories have used the discharge of a suitable condenser to simulate the actual line condition. For this purpose, and for the study of the action of insulation and gaps, impulse generators have been built which may be charged to values as high as 2,000,000 volts.

The calculation of such transients is not troublesome so long as the voltage is low and the wave front not too steep. However, with the higher voltages and very steep wave fronts, assumptions are often made, the correctness of which is at least open to question. The sphere gaps which are used are assumed to be instantaneous, and the resistance of the gap after arc over is assumed to be negligible. The inductance and capacitance of the connecting leads is often neglected, while the influence of the test piece itself on the wave shape is frequently unknown. The circuit usually comprises loops which anyone familiar with radio knows are likely to mean coupling that may give rise to erroneous results.

The limitations and some, at least, of the possible sources of error involved in the use of the impulse generator have been recognized by lightning-arrester engineers for some time. Three years ago the authors began to search for means of recording, on a photographic film, transient phenomena the frequency of which might be a million cycles per second or more. As a result of this search of the literature, the device described in this article was found.

Oscillographs

The frequency limit of the ordinary Duddell oscillograph is in the neighborhood of 15,000 cycles. At this frequency the errors due to mechanical inertia are large and it is impossible to do more than count the cycles; the wave form cannot be distinguished.

A satisfactory oscillograph for the delineation of the volt- or current-time characteristic of a short-time transient must satisfy the following conditions.

1. The device must have no appreciable inertia and must be capable of operating at a frequency of at least one million cycles per second.
2. The device must use little energy in its operation, so that its use will not appreciably disturb the original circuit.
3. The device should be capable of registering both voltage and current simultaneously.
4. The apparatus must be so arranged that a single impulse will be sufficient for a satisfactory photographic impression.
5. The oscillograph should be as simple as possible and have sufficient accuracy so that the results may be used with confidence.

The first point can be satisfied only by some device using the flow of electrons. When thinking of the available devices making use of such a flow, one naturally turns to the Braun tube which has been used for many years as an oscillographic device. As originally developed, the Braun tube consisted of a cathode and an anode in an exhausted tube, together with a fluorescent screen. Unidirectional voltage from a static machine causes a flow of electrons from the cathode to the anode, some of which pass through a small hole in the anode and are deflected by magnetic or electrostatic fields produced by the phenomena being studied. The rays then pass on to the fluorescent screen where a graph is traced the coördinates of which are determined by the deflecting fields. If the phenomenon repeats itself, the graph appears as a stationary pattern, and may be recorded photographically using an exposure of several seconds.

The Braun tube has negligible inertia, and very little energy is required to cause the deflection of the cathode beam. Its speed is the speed of the electron which may be varied between quite wide limits especially if using a heated cathode as in the Western Electric tube(1). The upper limit of velocity is perhaps one-half that of light.

The fourth condition mentioned, that of recording a single impulse, may be satisfied by placing the photographic film inside the tube in such a way that the electron stream impinges directly on the film. This has been done by several investigators with marked success. Some additional photographic effect can probably be obtained by the use of the heated cathode, but to get high electron velocities a very good vacuum is required which makes the operating technique more difficult.

Many references have been found in the literature concerning the Braun tube and its uses. Most of this material has been the result of investigations done in foreign countries. All of the early work was done with fluorescent screens which limited the oscillograph to use with phenomena which could be duplicated, since the time of exposure was very long compared to the duration of most transient phenomena.

S. R. Milnor(2) in 1912 reported a volt-ampere characteristic of an arc at a frequency of two million cycles. This work was done with a cold cathode and a fluorescent screen, but he was able to make the phenomena repeat itself exactly.

The first reference to the use of the photographic film inside the tube appears in an article by Alexander Dufour(3) in 1914. He stated that he had obtained on a film a space of 1 millimeter corresponding to an interval of time of one three-millionths of a second. Dufour succeeded in doing this by the use of a method of registration which is described more in detail later in this paper.

In 1919, Sir J. J. Thompson(4) in a lecture before the Royal Institution stated that, when using a hot cathode with the film inside the tube, an exposure of one-hundred thousandth of a second would be sufficient to excite the photographic plate. This reference also mentions the use of an auxiliary deflecting alternating current which produces the time axis and which could also be used for timing the phenomena.

In a valuable contribution appearing in the *L'Onde Electrique* in 1922 Dufour(5) describes a cathode ray tube which he used successfully with transients up to a fundamental frequency of 750,000 cycles with harmonics showing plainly at a frequency of 3,000,000 cycles. To produce a time axis, Dufour used the rise of current in an inductive circuit to draw out continuous oscillations from an arc generator. He used a cold cathode with the photographic plate inside the tube, the tube being connected to a continuously operating air pump. This apparatus was used in studying the antenna currents in the wireless system on the Eiffel Tower.

In 1921, Dr. D. A. Keys,(6) in an article entitled, *A Piezoelectric Method of Measuring Explosion Pressure*, used a cathode oscillograph as the indicating device for the determination of instantaneous pressures in explosions under water. In this work Dr. Keys used a heated cathode with the photographic plate inside the tube.

In 1922, Johnson(1) described a tube developed by the Western Electric Company, which makes use of the hot cathode. This tube has a much higher sensitivity than the cold cathode tube used by Dufour. With any given tube the sensitivity depends on the speed of the electrons in the cathode stream and on the deflecting force. If high sensitivity is required, the use of the heated cathode will give very good results as it is possible to apply low cathode voltages and secure slow moving electrons. Since the cold cathode depends on positive ion bombardment for the liberation of electrons, quite high voltages are necessary, which means high velocity electrons.

The name of Professor Harris Ryan(7) has been associated with the cathode ray oscillograph for many years, he having had a paper on this subject before the American Institute of Electrical Engineers, as early as 1903.

Important work has been done by several investigators among whom may be mentioned Wood,(8) Minton,(9) and Chaffee,(10) but enough have been mentioned to indicate the development of the cathode ray oscillograph in recent years.

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(1) J. B. Johnson, *Journ. Am. Opt. Soc.* and *Review Opt. Inst.*, Vol. 6, pg. 701, Sept. 1922.

(2) S. R. Milnor, *Phil. Mag.* Vol. 24, pg. 709, 1912.

(3) A. Dufour, *Comp. Rend.*, Vol. 158, pg. 1339, 1914.

(4) *Engineering*, April 25, 1919, pg. 543.

(5) A. Dufour, *L'Onde Electrique*, Nov. 1922, Vol. 1, pg. 638-663.

(6) D. A. Keys, *Phil. Mag.*, pg. 473, Oct. 1921.

(7) H. J. Ryan, *A.I.E.E. Trans.*, Vol. 20, pg. 1417, 1903.

(8) A. B. Wood, Phys. Soc. of London, Dec. 18, 1922.

(9) J. P. Minton, *A.I.E.E. Trans.*, Vol. 34, pg. 1115, 1915.

(10) E. L. Chaffee, *American Academy of Sc.*, Vol. 47, November, 1911.

The Dufour Oscillograph

For the study of high-speed transients then, it appears that no better device is available than the oscillograph developed by Dufour.

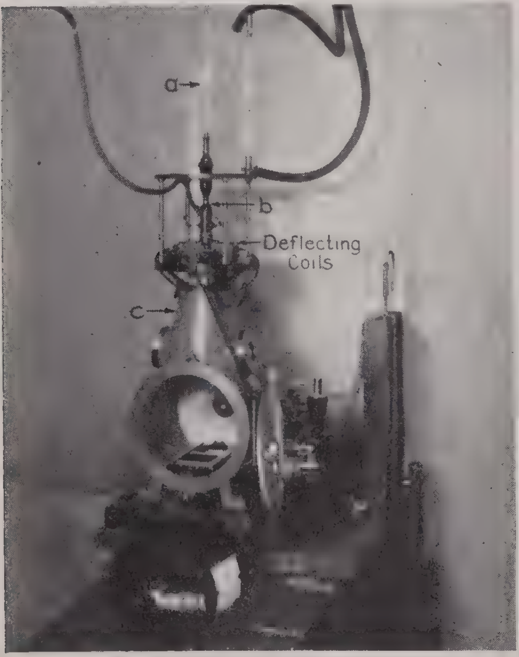

Fig. 1. Dufour Oscillograph

In the description of this oscillograph which follows, the tube itself is identical with that described by Dufour(5). The switching apparatus furnished by Dufour has not been used in this investigation.(11)

Referring to Fig. 1, the oscillograph consists essentially of glass tubes *a* and *b*, fitted by means of a ground joint into the bronze chamber *c*. The upper glass tube *a* carries the cathode and anode. The tube *b* has one pair of deflecting plates for electrostatic deflection of the electron stream. For magnetic deflection two sets of coils, 1—1 and 2—2 (Fig. 2), perpendicular to each other, are placed external to the tube and located slightly below the deflecting plates. The coils are arranged so that they may be rotated about the axis of the tube, thus allowing adjustment of the angle between the axes of the deflecting fields.

To operate the oscillograph expeditiously, easy means must be provided for changing films quickly. It is also necessary that a fluorescent screen be arranged so that it can be removed when making an exposure. How this is done in the Dufour oscillograph may be seen by referring again to Fig. 1. The drum, which in the illustration appears in the foreground, is provided with a film magazine which allows six films to be taken in succession. When viewing the phenomena, a fluorescent screen is turned up into position covering the opening into the interior of the drum so that the films are not exposed when using the screen. After placing the films in the drum, it is placed inside the bronze chamber and locked in position. The opening is closed by a door having a very carefully constructed joint so that the tube may be made air tight. Three cocks, turning in ground joints placed in the door, serve to operate the mechanism for changing films and moving the fluorescent screen. Two glass windows, one on either side of the bronze chamber, permit of easy view of the fluorescent screen.

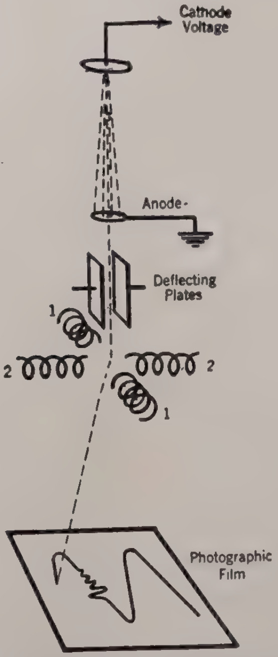

Fig. 2. Diagrammatic Representation of Oscillograph Operation

Operation of the Oscillograph

For slow speed work a moving drum to take the place of the magazine drum may be used. This drum is driven by means of an external motor and magnetic clutch. A simple calculation shows that such a drum cannot be rotated at a sufficiently high velocity to draw out the oscillations so that they may be studied. To draw out a one million-cycle wave in a manner similar to that used with the ordinary Duddell oscillograph, so that two millimeters are allowed per cycle, would require a film velocity of 2000 meters (6650 feet) per second.

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(11) For a description of this part of the apparatus reference should be had to the work of Dufour.

This problem has been solved by Dufour in a very satisfactory manner. Rather than move the film, the electron stream is subjected to the action of auxiliary fields which draw out the wave without the limitations of a mechanical system, as shown in Fig. 2. The method by which this is accomplished may be understood by reference to Fig. 3. In I is shown the effect of passing a transient current through coils 1—1. With the proper circuit arrangements the beam is held off the film at the top until ready for the photograph to be taken, when a transient takes place which sweeps the beam across the film holding it off the film at the bottom. This transient current will be referred to as the sweeping current.

A source of high frequency (a vacuum tube oscillator) is connected to coils 2—2, which are mechanically spaced 90 deg. from coils 1—1.

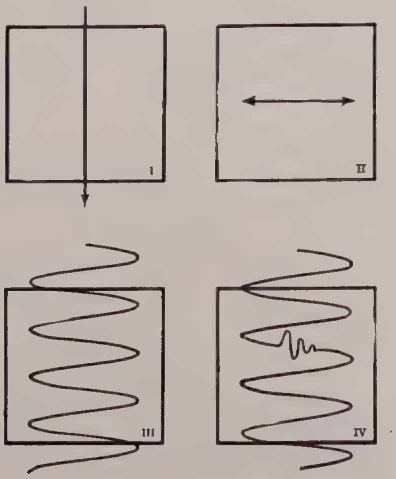

Fig. 3. Method of Registering Transient Phenomena

I. Sweeping III. Sweeping and Oscillator
II. Oscillator IV. Transient superimposed on III

With coils 2—2 energized, the oscillator traces a straight line on the film, the amplitude usually being adjusted to utilize the entire width of the film. When coils 1—1 and 2—2 are operated together the oscillator waves are drawn out as seen in III. If the oscillator frequency is 50,000 cycles and the effective width of the film 100 m. m. (3.9 in.), then the average distance corresponding to one micro-second would be 10 m. m. (0.39 in.). This means that if a million-cycle wave was impressed on the deflecting plates so that the beam was deflected thereby in the same direction as by the sweeping current, it would be drawn out sufficiently so that the wave form could be determined and IV shows the effect of the combination of the three fields. The oscillator wave is the zero line for the transient being studied and it is a time axis whose unit of measure is varying according to the sine law. The speed of sweeping is always a compromise between drawing out the oscillator wave and the difficulty of getting the unknown phenomena timed so as to appear on the film. With much slower speed phenomena, the sweeping field may be placed 90 deg. from that of the unknown transient, so that the time axis becomes a straight line across the film. This axis may be conveniently calibrated by superimposing a known high frequency using the oscillator coils.

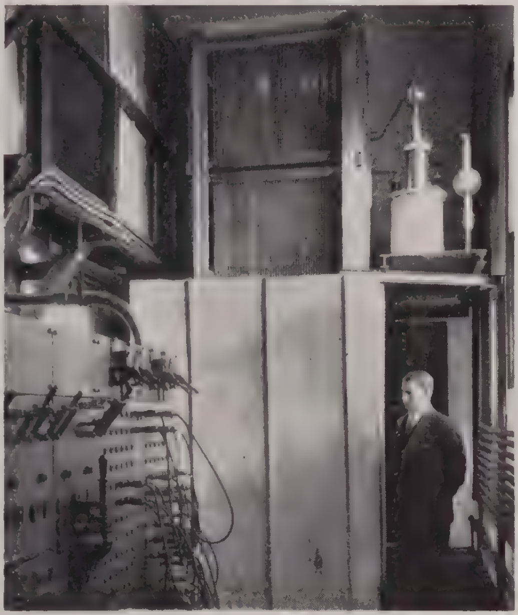

Fig. 4. Impulse Generator

Thus it is possible to get volt-time or ampere-time curves with a time axis which can be calibrated with considerable accuracy. Volt-ampere characteristics may be taken by applying to the cathode stream, fields proportional to the voltage and current and spaced 90 deg. apart.

The Cathode Stream

The best registration on the film is obtained when conditions are such that a fine pencil of rays strikes the film only when required. Not only is it desirable to hold the rays off from the film before and after the transient, but the operation of the tube is much improved if the cathode voltage is applied for just sufficient time to allow the proper registration of the unknown transient.

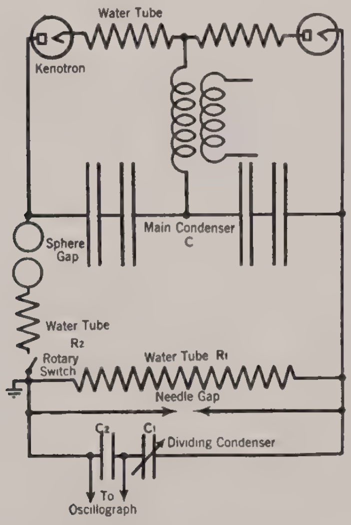

Fig. 5. Connection Diagram

For a given voltage impressed on the cathode the sharpness of the trace on the film will depend on the degree of exhaustion of the tube. For the work described in this article the authors have used a Langmuir condensation pump,(12) backed up by a two-stage oil pump. A McLeod gage was used to give an indication of the condition of the vacuum but the appearance of the spot on the viewing screen and the character of the discharge from the cathode itself, as viewed with the eye, gives a more accurate determination of the proper operating condition. A small tray of phosphorous pentoxide was kept inside the vacuum chamber which served to keep the vapor pressure low. The entire tube is always kept in the evacuated condition except when actually changing films. This procedure aids in keeping the gas evolved by the walls of the tube down to a sufficiently low value so that the tube can be worked easily and quickly.

The necessary cathode potential may be obtained by the use of either a high voltage direct current, or a few degrees of the crest of an alternating potential. The latter method may only be used with phenomena which are fast compared to the change of potential during its registration. This method was mentioned by Dufour as being particularly adapted to the study of very short time transients, and as this method is very convenient it was adopted for use in this study of gap characteristics.

Timing the Transient

The spot made on the photographic film by the electron stream may travel as fast as 80 km. (50 mi.) a second across the film; and since it is not feasible to get a developed registration length of more than 10 or 12 meters (32.8 to 39.2 ft.) on the film, the transient must be initiated during the very short interval of time in which the spot is sweeping across the film.

A rotary switching device has been built which makes the necessary contacts so that voltage is applied to the cathode, the sweeping started and the unknown phenomenon so timed as to appear on the film. The oscillator is connected before voltage is applied to the cathode, and remains connected until after the exposure has been made. The arrangements are such that only the pushing of a button is required to set in operation a mechanism which makes all connections automatically.

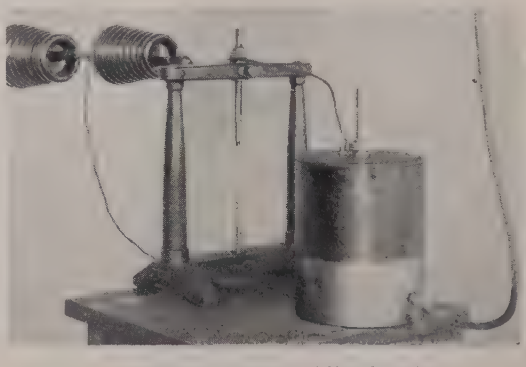

Fig. 6. Dividing Condensers and Test Needle Gap

Time Lag of Needle Gaps

It is known that a needle gap shows considerable lag when subjected to steep wave front impulses. The brief study which is presented herewith measures definitely the lags encountered under the given conditions. The results are not complete, but do give for the first time, as far as the authors are aware, a direct measurement of lags as short as a few micro-seconds. The methods used here are being applied to the study of the problems encountered in lightning arrester practice and will yield results of great importance.

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(12) Described in Dec., 1916, issue of General Electric Review; page 1060.

The time lag of a gap may be taken as the time elapsing until breakdown occurs during which the applied potential exceeds the low frequency spark potential. For a voltage only slightly in excess of the low frequency spark potential the time lag may be long, while with steep wave fronts of high voltage it will be extremely short. The lag with any given gap is determined not only by the voltage at the time of spark-over, but also by the shape of the wave front used.

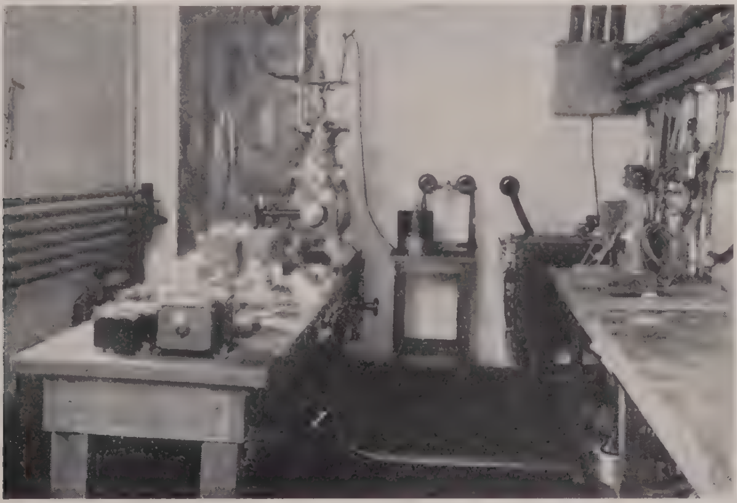


Fig. 7. Laboratory Set-up for the Study of Impulses

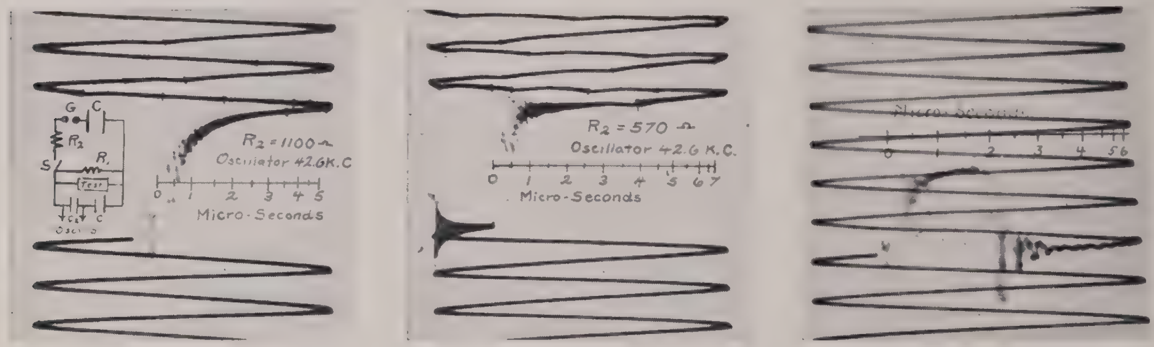
The purpose of these tests is to find the effect of successive increments of overvoltage on the time lag. To avoid the complication of a sloping wave front, it was thought best to use as nearly rectangular a wave as could be obtained. It is impossible to produce a perfect rectangular wave but if the time required for the voltage to reach a constant value is small in comparison with the time taken by the gap under test to spark over, the error will be negligible.

Test Arrangements

An impulse generator, which was built for use in connection with the testing of lightning arresters, was used as a source of voltage. This generator, which may be operated up to 100 kv., consists of two hundred glass plates with tinfoil coatings. The plates are divided into four groups connected in series, each group consisting of 50 plates in parallel, giving a capacity of 0.13 microfarads. The photograph (Fig. 4) shows the compact arrangement of the plates and the kenotron equipment which is used to charge the condenser. A connection diagram is given in Fig. 5 and shows the limiting sphere gap which determines the voltage at which discharge will take place. The water tube resistance, R_1, allows the sphere gap to charge up properly, while R_2 is used to control the wave front as will be shown later. The dividing condensers, C_1 and C_2, were used for reducing the voltage to the proper value for the deflecting plates on the oscillograph. The use of a resistance potentiometer was considered, but if a value low enough to record the wave form accurately was used, it would discharge the condenser too rapidly so that the voltage applied to the needle gap would not be sustained.

The oil-immersed dividing condensers are shown in Fig. 6, together with the needle gap being tested. These condensers consist of two fixed plates spaced 0.8 mm. (1/32 in.) with a movable third plate having a micrometer adjustment. The capacity of C_1 at the setting used on the tests was about 20 micro-microfarads. Variable stray capacities to ground and inductive effects between the condenser and the oscillograph were eliminated by using a ground shield around the dividing condenser and by the use of a concentric cable connection to the oscillograph. The grounded sheath of this cable was made of braided bronze wire, the inner conductor being a fine manganin wire having a resistance of about 100 ohms. This resistance was used to damp out oscillations originating in the dividing condensers and lines.

Voltage calibrations were obtained from capacity measurements, and more directly by taking oscillograms when holding a known 60-cycle voltage on the dividing condensers.



Film 300 Film 304 Film 593

Fig. 8. Oscillograms Showing the Wave Front Used on Needle Gap Tests

The general arrangement of the different elements used in taking a cathode ray oscillogram is shown in Fig. 7. The vacuum tube oscillator may be seen just in front of the oscillograph. The vacuum pumps are not visible, being located under the table directly beneath the oscillograph. The rotary switch is housed in the square box shown at the right. Between the rotary switch and the oscillograph are located the dividing condensers and the test needle gap. The entrance bushings back of the test gap lead to the 200-plate condenser, which is located close to the other side of the wall. When setting up this circuit, care was taken to make all connections as short and direct as possible.

Wave Form

Fundamentally, the circuit shown in Fig. 5 represents the discharge of one capacity into another with small series inductance and considerable series resistance. The circuit is of course complicated by the use of series gaps, wires leading to oscillograph, etc. With such a circuit, the series resistance R_2 will increase the time required to charge the capacity of the dividing condenser and connections.

The effect of changing R_2 may be seen by referring to Fig. 8, which shows the wave fronts with three different values of resistance. The method of registration used is the same as that described in connection with Fig. 3 and consists in applying an upward sweeping motion, combined with the horizontal motion of the oscillator. Superimposed is the discharge of the condenser which is initiated by the action of the rotating switch.

On the oscillograms given in Fig. 8 will be found two sets of oscillations, the first being damped out rather quickly. This oscillation, which has a frequency of approximately 20,000 kilocycles, occurs when the rotating switch sparks and is followed by another when the limiting gap sparks. There is a certain variable time interval between the sparking of these two gaps. However, for the purpose of this article the wave to be studied is that found when the limiting sphere gap sparks. On each of these films time is measured along an oscillator wave beginning at the time when the main condenser discharge begins.

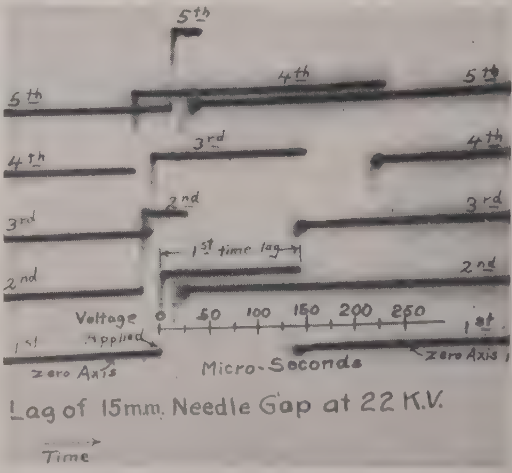


Fig. 9a. Oscillogram Showing the Time Lag of Needle Gap
Film 543—Five tests on needle gap at 15 mm. 22 kv.

In making these tests the aim was to obtain a steep wave front but at the same time to prevent the voltage from over shooting. Film

300 (Fig. 8) shows the main transient rising to its maximum value in about 2.5 micro-seconds. Superimposed on this wave front are oscillations which are made up of a combination of several frequencies. Film 300, which was taken with 1100 ohms in series, shows that none of the oscillations has a voltage exceeding the maximum value of the main transient.

The series resistance was reduced to 570 ohms and film 304 taken. This film shows that the main transient rises to its maximum in about 0.4 micro-second. This resistance is too small, however, as some of the crest values of the superimposed oscillation exceed the final voltage.

A value of 700 ohms was chosen as being the best compromise between the steepness of wave front and the condition of over-shooting. Film 593 was taken, using this series resistance, and it was found that a time of one micro-second was required for the voltage of the main transient to reach its full value (marked *a* on the film). This film is interesting as it shows the sparking of a needle gap 0.8 micro-second after full voltage had been applied.

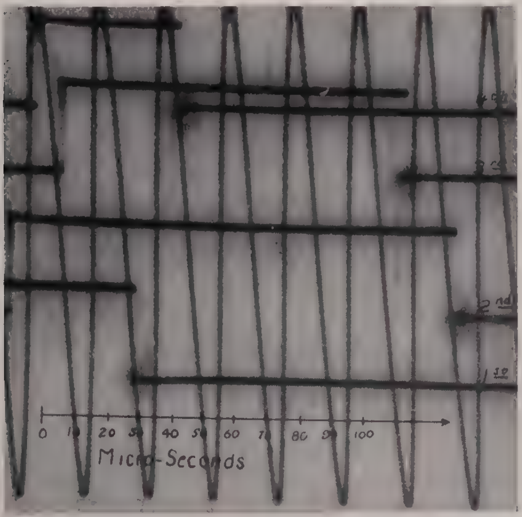


Fig. 9b. Oscillogram Showing the Time Lag of Needle Gap
Film 558—Four tests on needle gap at 60 mm. spacing, 58 kv., 50 kc. Timing wave.

Results of Tests

The time lags under most test conditions used exceeded two micro-seconds, which made the use of the oscillator undesirable except for timing purposes; therefore, nearly all results were taken with the sweeping only, as this allowed several exposures on one film. With six films and five tests per film, it was possible to get 30 tests before releasing the vacuum and changing the magazine drum. The use of the sweeping also gives a uniform time scale for the measurement of the lag.

The results of nine representative tests are given in Figs. 9a and b. As this type of oscillogram is probably new to most of the readers of this article, a brief explanation is given. The different tests are numbered in the order in which they were made. In the first test, for instance, which is at the bottom of the film, (No. 543), the cathode spot comes on the film from the left, being swept across the film at a uniform rate corresponding to 4.5 micro-seconds per mm. About 190 micro-seconds later the voltage is applied by the operation of the rotating switch. The cathode beam is deflected upward and traces a horizontal line, parallel with the zero axis, until after 140 micro-seconds the needle gap under test breaks down and the cathode spot falls to zero and so continues, passing off the film at the right. Although the wave front in this film appears perpendicular, it is really as shown in Fig. 8, film 593.

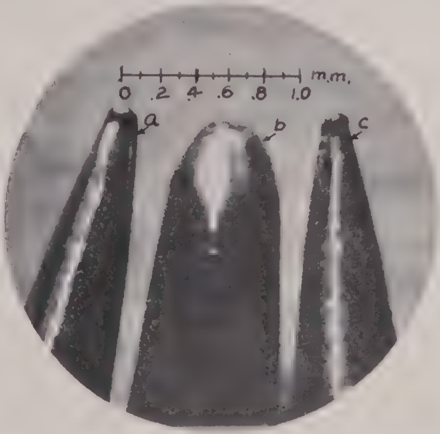


Fig. 10. Condition of Needles After Thirty Discharges
a. New point b. Dulled point
c. Extra sharp point

Four needle-gap breakdowns are given in film 558, Fig. 9b, the voltage being 5 kv. with a needle gap spacing of 60 mm. This film shows a 50-kilocycle timing wave which fixes the time calibration. Fig. 9a, Film 543 shows the result of tests on a 15 mm. needle gap with 22 kv. applied. These oscillograms show very nicely the steepness of the wave front compared with the time lags; and also how well the cathode ray oscillograph is adapted to the study of short time phenomena.

Results obtained from a series of oscillograms for three different voltages and with different needle-gap spacings are given in Tables I to III. Tests were also made with a needle to a plane and between needles having different degrees of sharpness. A photomicrograph is given in Fig. 10 showing the different needle points magnified to 30 diameters. This picture shows the condition of the needles after each had been given thirty discharges.

An analysis of the results given in these tables brings out certain relations which are briefly discussed.

For each voltage used, the gap setting, corresponding to infinite lag, will be slightly above the 60-cycle setting for that voltage. As the voltage applied to the gap decreased about five per cent in 4000 micro-seconds due to leakage of the condenser, no attempt was made in these tests to get extremely long lags

TABLE I

TEST DATA—LAGS GIVEN IN SAME ORDER AS TESTS WERE MADE—VOLTAGE 22,000

Spacing and Gap	Atmospheric Conditions	Time (a) Calibration Micro-seconds Per m.m.	Time Lags in Micro-seconds	Max. Min. Av.	PER CENT SPARKING (b)			
					1st Range	2nd Range	3rd Range	4th Range
18.5 m.m. Needle Gap	Bar. 29.03 in. Temp. 21.5 deg. C.	18.5	354–710–354–222–205 112–205–615–298–850 93–760–205–205– 55 240–280–850– 75– 75 370– 93–175	Max. 850 Min. 55 Av. 323	48	30	0	22
15 m.m. Needle Gap	Bar. 29.03 in. Temp. 22 deg. C. for 1st 34 tests. Rel. humidity 22 per cent Bar. 29.3 in. Temp. 18 deg. C. for next 10 tests. Rel. humidity 55 per cent Bar. 28.5 in. Temp. 21 deg. C. for last tests.	4.5	140– 19– 25–210– 13 120– 27– 18– 50– 34 120–100– 73– 18– 18 18–145–160–170 272–236–244–226–226 280–122–258–240–218 140–140– 23–172–191 145– 23–204– 18–272 23–245–145– 45–136 222–182–182–163–172	Max. 280 Min. 13 Av. 132	32	18	26	24
15 m.m. Needle Gap Extra Sharp Points	Rel. humidity 28 per cent Bar. 28.5 in. Temp. 18 deg. C. for 1st 10 tests. Rel. humidity 55 per cent Bar. 28.5 in. Temp. 21 deg. C. for last tests.	4.5	181– 90– 14–136– 41 75–115– 81–213–107 100–127–226–204–236 23– 27–272– 23–250 264– 82–240–136–226 182–190–226–168–190	Max. 272 Min. 14 Av. 147	17	33	20	30
15 m.m. Needle Gap Dulled Points	Rel. humidity 55 per cent Bar. 28.5 in. Temp. 18 deg. C. for 1st 10 tests. Rel. humidity 55 per cent Bar. 28.5 in. Temp. 21 deg. C. for last tests.	4.5	86– 14– 90–158– 14 208–100– 82– 45– 59 177– 18– 9– 13– 13 23– 23– 32– 9– 14 172– 19–218– 18–172 226– 18– 13–132–100	Max. 226 Min. 9 Av. 75	53	20	7	20
12 m.m. Needle Gap	Bar. 29.05 in. Temp. 22 deg. C. for first 20 tests. Rel. humidity 32 per cent Bar. 28.5 in. Temp. 22 deg. C. for remaining tests.	1.75	4– 19– 7– 5– 19 4– 7– 42– 10– 7 3.5– 42– 7– 7– 31 21– 2– 4– 9– 4 5– 16– 4– 7– 9 5– 27– 62– 35– 43 5– 4– 14– 9– 60 43– 9– 9– 46– 32 5– 35– 4– 43– 26 21– 16– 50– 64– 26	Max. 64 Min. 2 Av. 16.1	57	19	16	8

(a) Time calibrations are given to show that the accuracy of time measurement is comparable at different lags.

(b) In many cases the lags occurred in definite zones and to show this in a comparative way the maximum lag was divided into four equal times the percentage of lags occurring in each of these ranges being given.

TABLE IA

TEST DATA—LAGS GIVEN IN SAME ORDER AS TESTS WERE MADE—VOLTAGE 22,000

(a)Needle to Plane—Needle Negative

Spacing and Gap	Atmospheric Conditions	Time Calibration Micro-seconds Per m.m.	Time Lags in Micro-seconds	Max. Min. Av.	PER CENT SPARKING			
					1st Range	2nd Range	3rd Range	4th Range
12 m.m. Gap New(b) Needles	Rel. humidity 55 per cent Bar. 29.3 in. Temp. 20 deg. C. for 1st 25 tests. Rel. humidity 26 per cent Bar. 28.6 in. Temp. 20 deg. C. for last 5 tests.	4.5	110– 9– 4–155– 9 4–100– 9– 9– 9 4– 9–140– 14– 9 Put in new needle 100–110–104– 86– 91 86–104–110–100–114 Put in new needle 32– 41–109– 66–133	Max. 155 Min. 4 Av. 62	41	7	41	11
Extra(b) Sharp Points	Rel. humidity 26 per cent Bar. 28.6 in. Temp. 20 deg. C.	4.5	126– 64– 32– 9–114 68–104– 86– 82– 32	Max. 126 Min. 32 Av. 74	20	10	40	30
Dulled(b) Points	Rel. humidity 26 per cent Bar. 28.6 in. Temp. 20 deg. C.	4.5	14– 66–380– 23– 18 380– 9– 9– 36– 9	Max. 380 Min. 9 Av. 94	80	0	0	20

(a) Plane was a disk 2½ in. in diameter.
(b) See Fig. 10 for degree of sharpness of points.

TABLE IB

TEST DATA—LAGS GIVEN IN SAME ORDER AS TESTS WERE MADE—VOLTAGE 22,000

Needle to Plane—Needle Positive

Spacing and Gap	Atmospheric Conditions	Time Calibration Micro-seconds Per m.m.	Time Lags in Micro-seconds	Max. Min. Av.	PER CENT SPARKING			
					1st Range	2nd Range	3rd Range	4th Range
18 m.m. gap	Humidity 57 per cent Bar. 29.3 in. Temp. 25 deg. C.	18.5	465–465–130–205–335 700– 37–240–410–410 150–260–220–700	Max. 700 Min. 37 Av. 338	22	35	28	15
16 m.m. Gap New Point	Humidity 26 per cent Bar. 28.6 in. Temp. 20 deg. C.	4.5	61–210–116– 66–188 77– 33– 61–232– 66	Max. 232 Min. 33 Av. 111	11	56	0	33
Extra Sharp Point			221–116–183– 28– 44 80– 28–110–188	Max. 221 Min. 28 Av. 108	45	11	11	33
Dulled Point			100–200–300–222–338 360–210–188–288	Max. 360 Min. 100 Av. 236	0	10	45	45
14 m.m. Gap	Humidity 57 per cent Bar. 29.3 in. Temp. 25 deg. C.	4.5	95– 9– 11– 13– 9 11– 13– 5– 9– 23 13– 18– 13– 18– 11	Max. 95 Min. 5 Av. 18.1 If 95 point is included	94	0	0	6
				(Av. 12.6 omitting 95 point)	7	43	29	21

The per cent overvoltage above the 60-cycle spark potential necessary to obtain lags of one micro-second or less was found to decrease with increased spacing.

With spacings of 10, 40 and 65 millimeters the per cent overvoltages are 75, 40 and 29 respectively. It is, of course, to be expected that the greater the per cent of overvoltage the shorter the time lag. The results show that this is true, in general, although wide variations in time lag occur with every setting and at all voltages.

TABLE II

TEST DATA—LAGS GIVEN IN SAME ORDER AS TESTS WERE MADE—VOLTAGE 58,000

Spacing and Gap	Atmospheric Conditions	Time Calibration Micro-seconds Per m.m.	Time Lags in Micro-seconds	Max. Min. Av.	PER CENT SPARKING			
					1st Range	2nd Range	3rd Range	4th Range
60 m.m. Needle Gap	Relative humidity 38 per cent Bar. 28. 5 in. Temp. 21 deg. C.	2.8	22– 14–251–251–182 33–215–212–296– 22 22– 48– 31–140– 28 48– 25–112– 28–134 36– 42– 45– 34– 14 87–210–196– 87	Max. 296 Min. 14 Av. 78	52	21	17	10
50 m.m. Needle Gap	Relative humidity 35 per cent Bar. 28.5 in. Temp. 20 deg. C.	4.5	13– 18– 68– 59– 9 136– 91– 68– 9– 68 91– 9– 9– 9– 9 9–100– 68– 9– 82 5– 77– 9– 9– 68 100– 68	Max. 136 Min. 9 Av. 47	48	4	44	4
45 m.m. Needle Gap	Relative humidity 15 per cent Bar. 29.1 in. Temp. 21 deg. C.	2.8	6– 25– 6– 3– 3 6– 6– 6– 6–112 6– 42--112– 6– 3 3– 3– 3– 3– 3 3– 3– 3– 63– 3 6– 39– 3– 6– 3	Max. 112 Min. 3 Av. 16.5	83	7	3	7

An examination of the tabulated results discloses the existence of time-lag zones, which indicates that break-down is more likely to occur within these zones than outside. The existence of these zones is doubtful in some cases, while in others it seems well defined, as for instance at 75 kv. with a 95-mm. spacing (Table III).

In general, the tests show that dull needles give shorter time lags than sharp needles, although more tests should be made to be certain of the relationship.

Comparing the point-plane tests (Point negative, Table IA) with the needle points having the same spacing the data show that the lags are of the same order of magnitude although the maximum lag with the point-plane is considerably greater than the corresponding value for the points. Tests made with the point positive (Table IB) show that the lag is less than two micro-seconds while with the point negative with the same spacing and voltage, an average lag of 62 micro-seconds was obtained. When the point was negative with a spacing of 13 mm. sparking occurred with approximately 50 per cent of the voltage applications. With the point positive a similar condition was obtained with a spacing of 19 mm. These results give some conception of the effect of polarity on the lag of a pointplane gap.

Measurements of atmospheric conditions were made as a matter of record. Although no correlation with the variation in time-lag could be found, these factors undoubtedly have a great effect. To determine the effect of these factors much greater variations are necessary than those which occur naturally.

Conclusions

An oscillograph is now available, as represented by that made by Dufour, by the use of which single transients may be photographed, without being limited by the inertia of a mechanical system. By its use, wave forms have been photographed having measurable oscillations up to 20,000 kilocycles. The authors have worked with an oscillator frequency of 250 kilocycles which allows the registration of a frequency of 100,000 kilocycles. As the frequency increases, the problem of the characteristics of the circuit used become increasingly important and great difficulty is experienced in keeping the oscillograph circuits free from disturbances emanating from the main impulse circuit. The cathode ray oscillograph, as used here, becomes a tool of the greatest value in the study of transient phenomena.

TABLE III

TEST DATA—LAGS GIVEN IN SAME ORDER AS TESTS WERE MADE—VOLTAGE 75,000

Spacing and Gap	Atmospheric Conditions	Time Calibration Micro-seconds Per m.m.	Time Lags in Micro-seconds	Max. Min. Av.	PER CENT SPARKING			
					1st Range	2nd Range	3rd Range	4th Range
95 m.m. Needle Gap 70 per cent sparking at this setting	Relative humidity 14 per cent Bar. 29.1 in. Temp. 22 deg. C.	8.5	120– 21– 88– 42– 25 491–406– 34–340–466 339–440–400–460–400	Max. 491 Min. 21 Av. 260	40	0	14	46
80 m.m. Needle Gap	Relative humidity 14 per cent Bar. 29.1 in. Temp. 22 deg. C.	5	35– 45–280–240–250 35– 40– 30–235– 30 35– 30– 35– 35–335 235– 40– 15–210–230 300–200–250– 45– 30 35– 35– 40– 35–210	Max. 335 Min. 15 Av. 120	58	0	28	14
72 m.m. Needle Gap	Relative humidity 26 per cent Bar. 28.8 in. Temp. 19 deg. C.	2.4	38– 38– 43– 48– 26 43– 29– 38– 21– 48 29– 45– 29– 29– 29 29– 2– 17– 55– 60 31– 53– 41– 31– 31	Max. 60 Min. 2 Av. 35	4	48	28	20

The lag tests, with constant voltage on the needle gaps, show that the lags vary between wide limits, the average lag increasing with increased gap settings. The limits could probably be narrowed considerably by the use of careful control of air and electrode conditions. The per cent overvoltage, required to keep the lag to two micro-seconds or less, decreases as the gap spacing increases. The lag is shown to depend on the condition of the needle, the dull needle tending to have the shorter lags.

The authors are continuing the use of the oscillograph, intending to apply it to the study of transients on transmission lines due to lightning and other causes. The breakdown of insulation and the operation of lightning arresters is also being investigated. Acknowledgment is gladly given to the work of Alexander Dufour, who constructed the oscillograph used by the authors in the work described in the paper.

Rural Electrification

By Robert H. Rogers

Industrial Engineering Department, General Electric Company

Electricity is constantly finding new fields of service; steadily removing the burden from human hands, doing the work faster, better, and cheaper. The present-day trend of electrification is toward the development of rural districts. The public utility interests are desirous of increasing their business while the rural population is looking forward to receiving the benefits of electricity. Naturally enough, a problem of vast interest is the subject of much discussion. The following article briefly outlines the situation, and reviews some of the problems and practical uses of electricity on the farm.—Editor.

Rural electrification is now prominently before the public and its problems are being studied by many independent or related organizations. The public utility interests are working out their part in the matter, the rural population is looking forward to the benefits of electricity now practically limited to city dwellers, and all phases of the subject here and abroad are receiving a great amount of publicity. This article briefly reviews the important new trend in electrification which promises a great boon to vast numbers of people.

The economics of this proposed widespread application of electricity present some interesting features. We find 50,000,000 people who would not know how to get along without electricity while an equal number of equally deserving people have never had an opportunity to make its acquaintance. The fact that half our population is ethically entitled to the benefits of electric service, enjoyed by the other half, lends strength to the recent prediction of Mr. Samuel Insul who said: "* * * it is bound to come and in the comparatively near future. The farmer is entitled to it and he will get it."

The rapid and general adoption of automobiles, radio, and telephones, and the greatly advanced standards of education now being insisted upon, indicate the desire and determination of the rural population to secure improved conditions. The purchasing power of this division of prospects is enormous as shown by the vast investments in lighting sets, gas engines, tractors, and other modern machinery and devices that are not necessities. This purchasing power is taking a strong upward trend, and more and more farmers are looking to electric service as coming well within their means.

The general well-being of the whole country is enhanced by those things that tend to make farm children willing to remain on the farm, and which tend to make the farmer satisfied to have his home on the farm rather than in some nearby city. Electric service with all that it offers is the greatest element, at the present time, that promises to bring contentment to rural people.

Markets for Service

The market for electric energy, outside of cities and large towns, divides into three groups. It is not confined to farms by any means, a fact that removes much of the difficulty in the way of general distribution.

There are first the hamlets, "four-corners," and ex-suburban rings of former city dwellers now bee keepers, shop keepers, entertainers of tourists, or otherwise occupied. These are communities of fair density that can be served by the public service lines and thus form points of departure for the more far-flung rural lines. The second type of market for electric energy includes the rural industries with which the highways are studded and which may be served by the judicious plotting of service lines. They give stability to the loads, are good revenue producers, and are readily fostered and developed in areas where electric power is available. In this class are found garages, blacksmith and wagon shops, quarries, brick and tile works, grist mills, grain elevators, creameries, canneries, and the like, the whole list running to great length.

The third and major division of course includes the farms, plantations, and ranches with great diversity of power requirements and a wide range of seasonal fluctuations.

Distribution

The distribution of power along thinly populated highways presents little difficulty beyond that of cost. Where rural extensions are common, the physical problems have been worked out fairly well though in many different ways. Alternating current is used without question, 110 volts or 110 and 220 volts are well standardized for service lines in and about buildings. Whether to use three-phase or single-phase is an unsettled question, both being commonly found. Three-phase motors are the simpler but single-phase distribution for short branches is preferred by the service companies.

It is not feasible to tap low-voltage service from the major high-voltage transmission lines, and therefore it often occurs that a farming region traversed by a transmission line is served by a lower voltage distribution system back-tracking from some city further down the line. In general, distribution for rural purposes is made at 13,000 or 6600 volts with some older lines at 2300 volts. Occasional peaks or heavy seasonal motor loads, as threshing for example, tend to disturb the voltage on these low-voltage systems. High voltage, say 13,000, permits the use of a size of wire chosen only for its mechanical strength, as it will have ample capacity for heavy loads now and then without undue voltage disturbance, especially as the actual current changes are much less at this high voltage.

Rural requirements have not yet been sufficiently established, as to maximum demand, diversity, and other characteristics, to give the degree of confidence in engineering transformer applications that prevails in city work of similar nature. The proper grounding of circuits, the best forms of lightning protection, and the minimizing of core loss and other losses are still subjects of study and discussion. Rate setting is the subject of much disagreement between the public service companies and the academic organizations that are fostering rural service. An equitable method seems to be based on separating service charges from energy charges, making the latter the same as city rates. The service charges may be financed by a minimum monthly bill, a deposit, or both. Such is the "Adirondack Plan" which is among the most practical so far submitted.

Advantages to Public Utility Companies

Public service companies from the frank scepticism of previous years have come or are coming to see the following advantages to themselves in a network of rural lines:

(a) An increased market for their product—the expansion outlet so desirable for any going concern.

(b) The broader spread of customers and good will adds stability to the business. Opposition to automobiles by farmers, it will be remembered, disappeared when the farmer got behind the wheel himself.

(c) Utilities that retail appliances and electrical merchandise, or who do wiring construction work, will increase that part of their business more than in proportion to a like increase in city customers, because the rural customers will look to their central station service for advice and equipment.

(d) Rural lines may help the central station to take advantage of a very modern development, the miniature automatic hydro-electric station (perhaps as small as 150 kw.) which operates by itself in some remote rocky glen. Rural lines might easily encompass such locations so that they may actually supply the locality with power while relying on the high-tension line only for control and continuity.

General Characteristics of Farm Drives

Coming now to the farm itself, there is a field of application with conditions very similar to those in city industries 20 years ago. Machinery designed for entirely different means of operation, namely, hand, animal, wind mill, steam engine, or gas engine, is not perfectly adapted to electric motor drive though in most cases the electric motor can make a good showing for itself even under these handicaps. Most farm machinery is designed for low-speed operation, at least at the point where power is applied, whereas electric motors are essentially high-speed units. Methods wasteful of power (because it was never measured) prevail, but the ever-watchful meter demands the adoption of methods that get the maximum of useful work out of each kilowatt-hour of energy. There is not much to be done in revamping machines, methods, and operations to adapt them in a preliminary way to the new servant. Co-operation between farm machinery manufacturers and the manufacturers of electric devices is improving this situation.

Chore machinery, which necessarily has a low load-factor, will not stand being loaded up with heavy motor investments. Portable general service motors such as the motor shown in Fig. 1, will suffice in many cases where the required services do not overlap and especially where the required work is of short duration daily, weekly, or seasonally. Fractional horsepower motors will generally be installed directly on the driven machines, whether for frequent or intermittent use.

Larger motors for special service will be "built in" or directly connected to machines where the hours of use per day justifies the investment.

In many cases it is likely that the chore motor (Fig. 1) will fill in during a transition period preceding the purchase of up-to-date equipment, and particularly during the time that the farmer is feeling his way to determine just what his needs are going to be under these new conditions.

The limitations of the pole transformer, as protected by fuses, must be learned in a practical way by the farmer to avoid interruptions of service due to the use of too many machines or devices at one time. In other words, a good load-factor is to be sought rather than the crowding of many functions into one hectic hour.

Utility of Electric Service

"For what can a farmer use electricity?" This question can be answered in so many ways that it is necessary to condense farm uses to a few items hoping that the leading applications will readily suggest others. There is sometimes a tendency to run this listing of applications to the point of absurdities, a practice that will tend to do more harm than good. The following are believed to be practicable applications, and proven to be so by every-day work.

The lighting of homes, barns, outbuildings, yards, drives, industrial plants, and community buildings certainly presents a variety of lighting requirements and a very respectable aggregate load.

Highway lighting which every year is becoming more in demand is an application well worth considering, by itself, in connection with rural systems.

Heating by electricity includes the cooking range, the cooking of stock feed, water heating, incubation and brooding in poultry operations, welding and vulcanizing in garages, sterilizing and related processes for creameries, canneries, and other kinds of food preparation plants. Refrigeration for homes, particularly those out of the natural ice zone, the cooling of milk, and other food product cooling in the local industries are among the desirable loads. The precooling of fruits before shipment or before going into cold storage is a comparatively new practice calling for refrigeration devices and electric motor-driven fans.

General farm motor applications include:

Wood sawing for fuel
Cross- and rip-sawing logs for lumber and lumber dressing
Pumping water to supply tanks
Pumping irrigation water
Turning grindstones
Ensilage cutters and blowers
Hay hoists
Grain and corn conveyors
Corn shellers
Corn crackers and grinders
Cob breakers
Grain cleaners
Attrition mills
Green feed choppers
Bone cutters
Concrete mixers
Line shafts for groups of dairy machinery such as milking machines, cream separators, churns, etc.

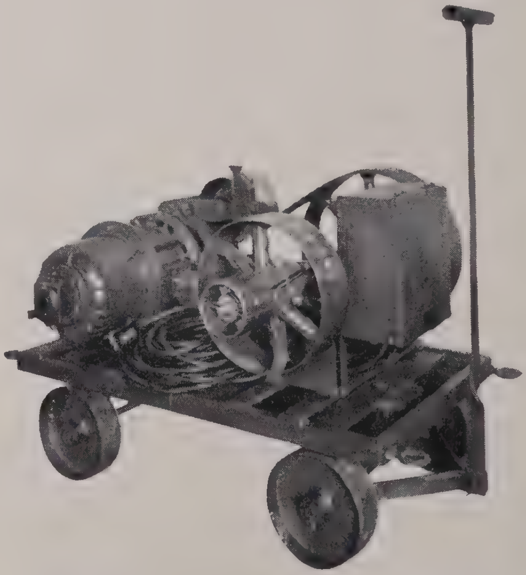


Fig. 1. G-E Farm Utility Motor. A portable power unit for use with belt driven machinery

Line shafts for laundry and small feed machinery
Line shafts for shop machinery such as emery wheels, grindstones, drill presses, saws, lathes, forges, etc.
Rock crushers for driveway material, concrete work or fertilizer
Rock pulverizers for fertilizer
Ice haulage and elevators
Ice chippers
Ice cream freezers for tourist stands
Churns
Milking machines
Cream separators
Washing machines
Clipping and grooming machines
Sausage grinders
Hay and straw balers
Cider mills
Threshing machines
Hullers and viners
Vegetable preparing machinery
Fruit and vegetable graders
Cotton gins

Power applications for all kinds of rural service are too numerous to catalog. They include however the normal household utilities; some 30 or 40 items of farm machinery, only a few of which are likely to be found on any one farm; and the great spread of community industries, and irrigation. The pumping of water is probably the most general of all rural power applications.

Group drives are of value for the smaller units, old-type units, and for short-time jobs of diversified nature. Some typical groups follow.

The repair shop group:
- Drill press
- Emery wheel stand
- Grindstone
- Forge
- Lathe
- Cross and rip saw

The house group:
- Washing machine perhaps to be replaced later by one having its own motor
- Pump to tank for house use. Individual motor with automatic switch may come later
- Fine meal grinder
- Churn
- Butter worker
- Poultry feed cutters and grinders

The barn group:
- Milking machine
- Cream separator
- Pump to tank for stock
- Stock feed preparing and blending machinery

There are certain operations for which electric motor drive is well adapted and which are not normally farm work although they find a valuable place when regular work is slack.

Crushed stone for driveways, for concrete, and for roofing when used with tar can be produced by a small plant where there is an outcrop or ledge on a farm. A profitable business may be built up with only a small outlay.

Pulverized limestone for conditioning land is being used in increasing quantities. Where the land in a given section responds to the treatment, there is the place for someone to establish a motor-driven crushing and pulverizing plant to use native rock. Crushed and pulverized limestone for land restoration is today a great industry with freight forming a heavy part of the cost to consumers. Local crushers can easily be established so as to limit road haul by truck to a few miles. This would give off-time employment, economical fertilizer, and a good load for the rural lines.

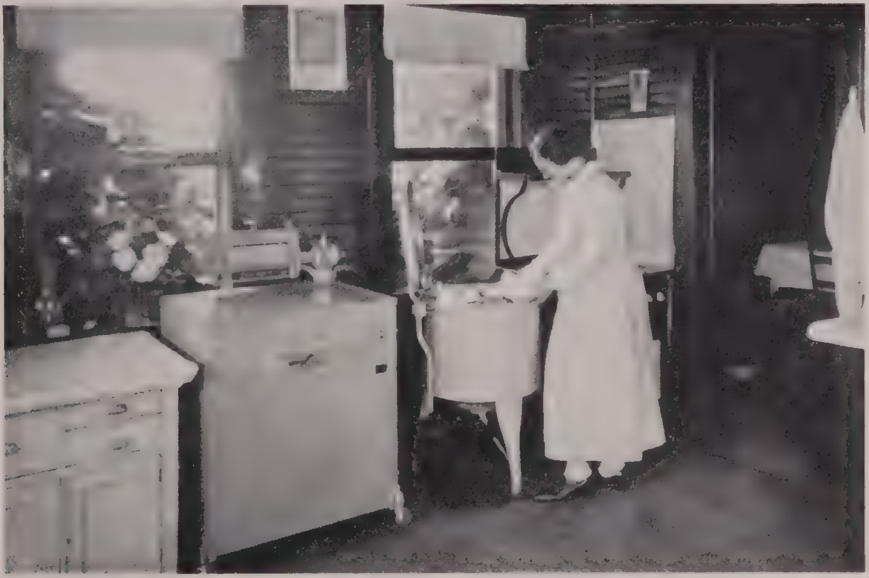


Fig. 2. A Farm Kitchen with Electric Washing Machine, Dish Washer and Range

Home-made concrete finds many valuable applications on the farm. Outbuilding foundations and floors, drains, walks, tanks, silos, fence posts, and the like can be made largely from material at hand and at times when regular farm work is not pressing.

The amount of power required for a really efficient concrete plant is small but is of such

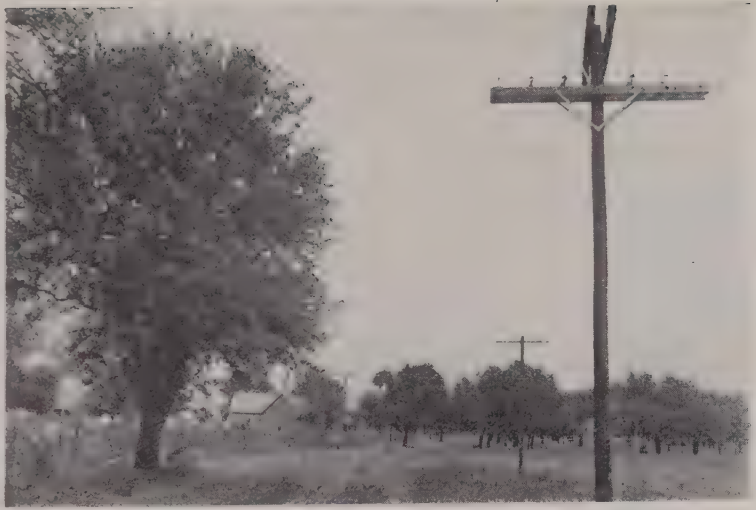


Fig. 3. Typical Power Distribution System for Rural Districts

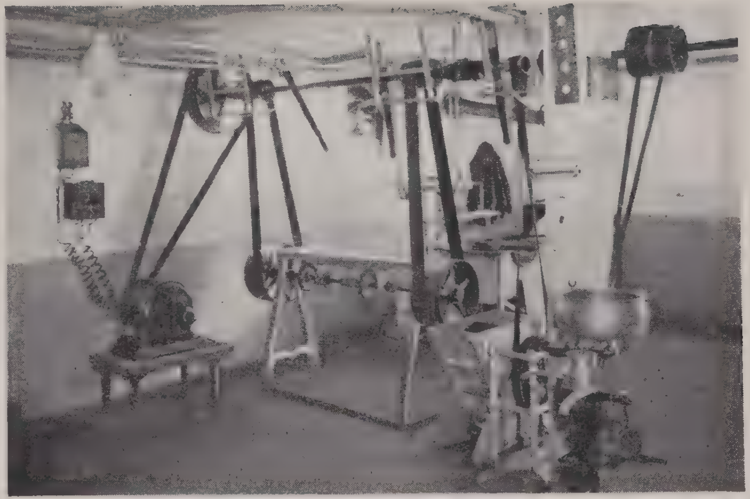


Fig. 4. A Motor-driven Dairy Group

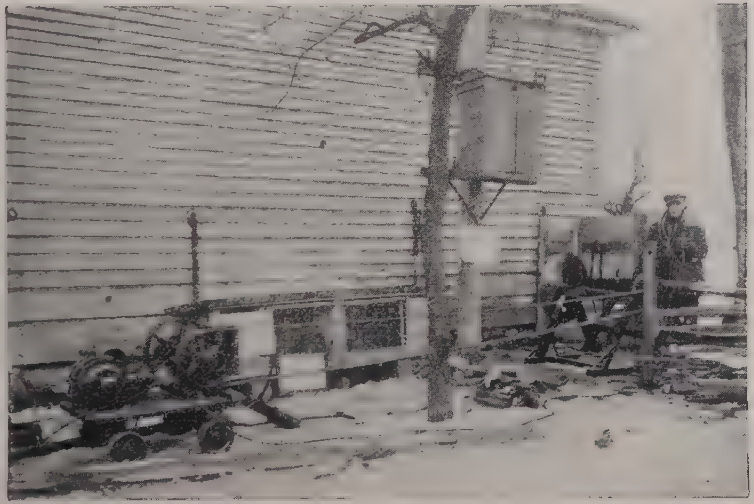


Fig. 5. Portable Motor for Use in Wood Sawing. Belt tension is maintained by bracing the truck with a ratchet jack

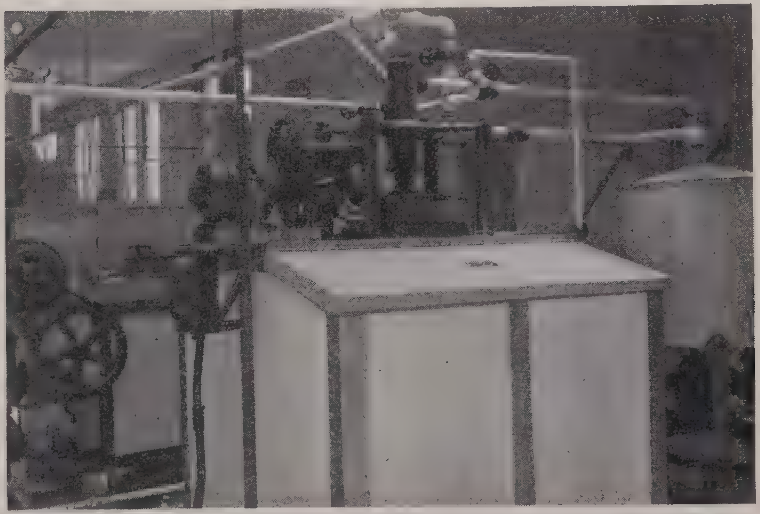


Fig. 6. Electric Drive in the Creamery, Demonstrating the Convenience of Individual Motor Application

a nature as to save a large amount of hand work. A pump may be installed and piping run from an existing water supply to furnish the necessary water. Where gravel is not available, a small rock crusher will give an aggregate superior to gravel. These machines may be belted to a line shaft with portable or fixed motor drive.

The manufacture of concrete fence posts, concrete blocks, or tile will in some cases offer a profitable side line. Many silos are now being built of pre-cast concrete staves, another saleable product.

The proper preparation of stock feed has a very favorable influence on the production of chickens and eggs, beef, pork, mutton, and all dairy products.

There are few farm activities that give as great returns as the work that is required to properly chop, grind, or blend the various feeds that are being converted into saleable products. Feed grinding takes a large amount of power, especially for fine grinding. It is now believed at many Agricultural Colleges that coarse grinding gives even better results and requires less time and power.

Much of the prepared feed now purchased can be duplicated or bettered on the farm by the use of inexpensive motor-driven cutting, grinding, and chopping machinery. These units will usually be operated one at a time, hence a portable motor can serve any or all in sequence. Corn lends itself to several methods of treatment for various feeds. The machines used are the corn sheller, cob breaker, corn cracker, corngrinder, and fine meal grinder. Some of these machines can be used on other grains or on mixtures of corn and grain, or on corn stalks with corn still in place.

Green-feed choppers and bone cutters are sure to increase poultry profits just as the well-known ensilage cutter does for the dairy.

Electric power used with fixed or portable motors makes these chores light and of short duration while the results are lasting and profitable. So much for applications.

Advantages to the Rural Community

In reviewing the many advantages of rural electric service, it has always seemed to the writer that its greatest selling point is overlooked or only incidentally touched upon in the various papers on rural electrification. The great distinction between life in the city and life in the country lies in the quantity of water used per capita. Electricity makes possible for rural homes these two major modern improvements, the modern bath room and running hot and cold water in the kitchen and laundry. Gas engines in a very few cases give a semblance of this convenience. The bath room and the kitchen-laundry water service that follows electricity far overshadow the usefulness of electricity used otherwise in the home, and it should be held up as a major selling point. City water conveniences in the country home will go far to make the rural home a most desirable dwelling place.

Furthermore, a constant and ample supply of water for stock and other outside uses is automatically made available by electric power thus giving every farm the equivalent of a hillside spring—a thing not to be rated lightly among the features worth while on the farm.

Safe, clean, carefree lighting of brightness far beyond anything attempted with oil, and used in the home, barns, outbuildings, and yard is probably the most obvious and best advertised advantage that electricity gives the consumer.

Where gas-engine power has been used, the continuity of service, the very low cost of maintenance, and the ease with which electricity is put to work and stopped has an immense appeal, especially so in freezing weather.

The shortening of the hours necessary for routine house work and for routine farm chores is appreciated wherever electricity is available. This gives the family more time for productive work, recreation, and general improvement, more time for the things that make life worth living.

From a straight dollars-and-cents standpoint there is hardly a rural customer who is producing anything saleable on his place who will not find production increased or cost of production decreased, or both, by the judicious use of electricity. This is where the utility companies can profitably build up a rural advisory staff for fostering the economic use of electricity outside the cities.

And finally, farms and other rural habitations and industries that are supplied with central station power are worth more to live on, to rent, or to sell than otherwise equally good property. In other words, every square foot of real estate along the rural electric line benefits by an increase in value with the arrival of electric service.

Automatic Substations for Railway Signaling and Train Control

By H. M. Jacobs

Railway Equipment Engineering Department, General Electric Company

There is no class of electrical apparatus which it is more important to keep in continuous operation than the signal and train-control systems used on railroads. Not only time and money are at stake, but often lives as well. Whether alternating or direct current is used, there must be an alternative power source for use in case of the failure of the normal supply. In alternating current operation, when one or both supplies are purchased from power companies, the delay incident to making the emergency changeover manually can be obviated by the use of automatic switching equipment, with the result that outages are reduced to a matter of a few seconds only. In this article Mr. Jacobs describes the type of equipment used and shows how automatic operation can bring to this class of service the same dependability and rapidity of action as is to be found in other automatic applications.—Editor.

A continuous supply of energy is a fundamental requirement in power-operated automatic railway signaling, whether direct or alternating current is used. This applies to both automatic signals and interlocking plants.

Signals operated by direct current receive their power from batteries, and therefore, from the standpoint of power failures, they are more reliable than signals operated by alternating current receiving their power from commercial sources. The continuous operation of an alternating current railway signaling system is, therefore, a direct function of the continuity of the power supply. For this reason it is the general practice to provide an emergency source, this being either alternating current of the same frequency, alternating current of a different frequency, or direct current derived from a power source or a storage battery. In all cases except where the reserve source is alternating current of the same frequency, converting apparatus is required.

Railway signaling is broadly divided into two general classes, "interlocking" and "automatic block." At certain points where there are switches, junctions, crossovers between tracks and sidings, etc., it is necessary for the government of train movements to control these devices manually from a central point. The various signals and switches must be so interlocked that a route may be established for a train, and other switches and signals interlocked in such a way that there will be no interference to the free passage of the train. In other words, the movements of certain levers in the signal tower to establish this route locks the levers controlling other signal functions. For this reason the territory under manual control, together with the signals and switches controlling mechanism and power apparatus for the operation of the signal devices, is termed an "interlocking plant." This is generally called an "interlocking." The load is, therefore, purely local. When a plant is operated from a storage battery, only one reliable source of power is required and this is used for charging the battery. If the plant is operated by alternating current, a reserve source of power that may be cut in with the least possible delay is imperative.

Automatic block signals are so termed because the indication for a train to stop or proceed is given automatically. This is accomplished through the medium of a low voltage circuit in the track, a typical diagram of which is given in Fig. 1. Insulated joints are placed in the rails at signal locations and all other joints are thoroughly bonded to reduce the rail resistance. These insulated sections are called "blocks." The relay for controlling the movement of the signal is connected across the rails at the entering end of the block and energy is applied to the rails either at the other end of the block or in the middle, depending on the type of signaling installed. The relay is energized when the block is not occupied. A train entering the block shunts the relay and sets the signal for a following train to stop. When the train leaves the block, energy is restored to the relay and the following train is given an indication to proceed. It is evident that an opening in the track circuit, which may be caused by a defective bond or a broken rail, or a failure of the energizing source, will cause a stop indication to be displayed. Batteries are the energizing source for a direct-current signaling system. An alternating-current signaling system derives its power from small transformers energized from a transmission line paralleling the tracks. The reliability of the system is, therefore, directly dependent on the continuous maintenance of power on the line; even a momentary failure causes a corresponding de-energization of the system, and every precaution must therefore be taken to insure continuity of power.

The power required for operating an alternating-current railway signaling system is comparatively small, and it is more economical and convenient to purchase it where possible than to generate it. However, power generated especially for signal service is more reliable than power purchased from a commercial system. No matter how reliable a commercial power system may be, there is no assurance against feeder trouble, particularly in overhead lines. It is therefore evident that as assurance against prolonged power outages it must be possible to supply the transmission line from at least two independent power sources; in other words, there must be a reserve source of power. This reserve source should preferably be a second commercial source, but may be a steam or internal combustion engine, or a generator set operating from a storage battery.

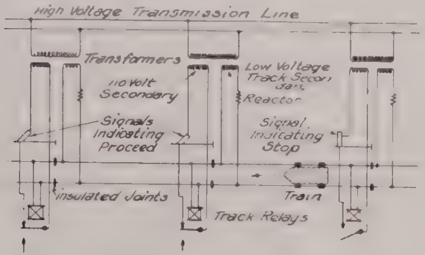


Fig. 1. Diagram of Fundamental Alternating-current Track Circuit

Interruptions due to power failure usually occur when least expected, and it may take considerable time for the person responsible for the operation of a manually operated substation to cut in the reserve power. The installation of automatic switching devices will eliminate delays inherent in hand switching.

Generally speaking, there are two classes of automatic substations for railway signaling, one for use in connection with interlocking plants or a short section of automatic signals, and the other for supplying power to automatic block signals, the normal and emergency power being fed to opposite ends of transmission line sections.

Comparatively few equipments of the first class have been furnished and no attempts have been made to standardize, owing to the special requirements that must be considered on each installation.

Two very interesting equipments were installed on the New York, New Haven & Hartford Railroad, one at Pawtucket, R.I., and the other at Stamford, Conn. Both of these plants are operated entirely by alternating current and the emergency power is obtained from a motor-generator set supplied by a storage battery. Under normal conditions the set is idle but starts automatically on failure of the normal source. The same set is used to charge the storage battery and is arranged to function automatically in case a power failure occurs while the battery is being charged. The Pawtucket equipment was described in the G-E REVIEW for January, 1916. The switching equipment is so arranged that a 5-kv.a. set will restore energy to the transmission line in 13 to 15 seconds from the moment of failure. The Stamford equipment is slightly larger but functions in about the same time.

There are a number of interlocking plants using a storage battery for the operation of switches and signals but having alternating-current track circuits and lights. The emergency power for the a-c. load is obtained from a small motor-generator set operating from the main storage battery which is charged either by another motor-generator set or by a rectifier. The automatic switching equipment is placed on the sub-panels of the control switchboard. Fig. 2 shows such an equipment installed on the Reading Railroad at Myerstown, Pa.

The first automatic substations for the operation of short sections of automatic block railway signaling consisted of one installation on the Grand Trunk Railway in 1914 and two installations on the Chicago, Rock Island & Pacific Railroad in 1915. These were all installed in the vicinity of Chicago and made use of the Pen Dell switch. In 1921 the Delaware, Lackawanna & Western Railroad installed an automatic switching equipment of the contactor type to supply about five miles of automatic signaling in the vicinity of Newark, N. J., using their 6600-volt, three-phase power line for the normal source, and Public Service Electric and Gas Company power for emergency (see Fig. 3). Although all these installations are of the first class; that is, a substation designed to supply a local load from two sources at one point, no attempt has been made to standardize. The Delaware, Lackawanna & Western station, however, is very similar to the present standards for automatic signals hereafter described.

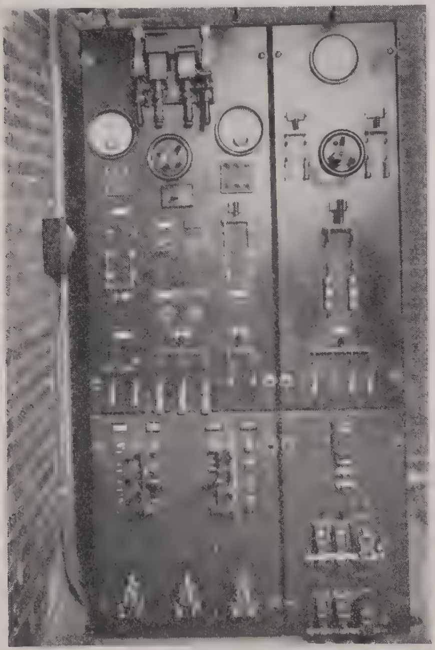


Fig. 2. Control Switchboard at Myerstown, Pa., Interlocking, Reading Company

The greatest application for automatic substations for railway signaling is in supplying power for automatic block signaling and train control.

On a long stretch of signaling, it is manifestly impossible and impracticable to supply the whole territory from one source of power. The distance over which power can be economically transmitted is determined principally by the load, the line voltage and the permissible line voltage drop; the higher the voltage, the greater the load that may be carried, or the same load may be carried a greater distance, for the same line drop. Expense is also an important factor, because the cost of high voltage apparatus and the pole line structure arranged for it, is greater than for low voltage equipment.

If the signaled territory is supplied from several sections of transmission line independently fed instead of from one long line, the loads in each section may be economically transmitted without using an expensive transmission voltage; the voltage of the signal apparatus is more uniform, due to decreased line drop, and the system is less subject to interruptions due to line trouble, because any disturbance is confined to the particular section in which it occurs. The length of sections will depend principally on the location of reliable power sources and the transmitted load.

It is now the common practice of many railroads to arrange their substation switching equipment so that each line section may be fed from either end. A line cut into two or more sections will therefore have a station at each of the extreme ends, and a station at the adjoining ends of two adjacent sections that can feed either section. For instance, a four-section line will have two end or "single feeder" stations and three intermediate or "double feeder" stations (see Fig. 4). Great care must be exercised to prevent the simultaneous connection of a line section to two independent sources.

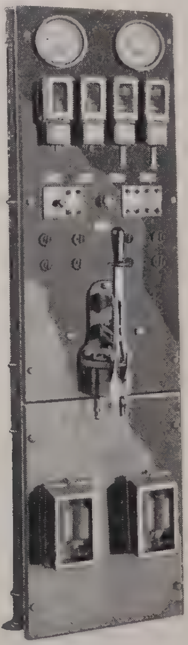


Fig. 3. Automatic Switching Equipment Delaware, Lackawanna & Western R.R., Harrison, N. J.

Manually operated stations may be so arranged that by proper co-ordination between the operators of two stations arranged for feeding one line section, the intentional change-over from one source to the other may be accomplished almost instantaneously. However, when the power fails at one of these stations, the line switch must be opened manually (or possibly by means of a low voltage tripping attachment), and the operator in the reserve station must be summoned to close his line switch. This may cause a delay of several minutes, whereas with automatic switching equipment installed in both stations, the change-over is practically instantaneous.

If automatic switching equipment is installed in each substation, extreme reliability of all power sources as regards power outages, is not essential. A line section may be normally supplied with power from a reliable source, using a less reliable source as the emergency; or the less reliable source may be considered the normal source if it offers a more favorable power rate. Automatic substations, therefore, make possible the purchase of power from some sources that, on account of outage conditions would not be considered satisfactory for sole dependence. However, a commercial source subject to unsteady voltage conditions, or single-phase failures should not be considered unless absolutely necessary. On account of the greater field for automatic switching equipments furnishing power to sections of transmission line for automatic signals and the similarity in operating requirements, it has been possible to develop certain standard arrangements. High voltage equipments of 2200, 4400 and 6600 volts, single-phase and three-phase, have been developed for signaling, or for signaling and train control combined, and quite recently single-phase equipments for 440 and 550 volts have been developed for a-c. automatic train control only.

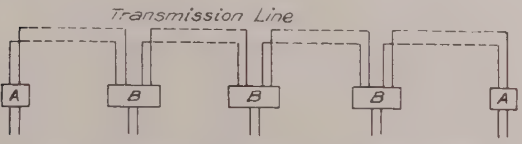


Fig. 4. Arrangement of Stations for Feeding Several Transmission Line Sections

The principle of operation of this type of automatic substation is very simple. Fig. 5 is the wiring diagram of a standard single-phase station taking power from a 2200-volt, single-phase source stepping up for 6600-volt transmission. For safety and economy, all switching is on the 2200-volt side of the power transformer, but it is sometimes advisable to do the switching on the high-voltage side to save exciting current losses from being carried over the transmission line.

The oil circuit breaker *No. 52* with time-limit overload relay *No. 51*, together with instrument equipment and customary protective equipment for incoming and outgoing lines, are required in an ordinary manually operated station. The automatic equipment includes under-voltage relay *No. 27*, auxiliary contactor *No. 27X*, master element relay *No. 1* with its potential transformer, control power transformer *No. 11*, contactor *No. 29*, and indicating lights. The functioning of these various devices is as follows:

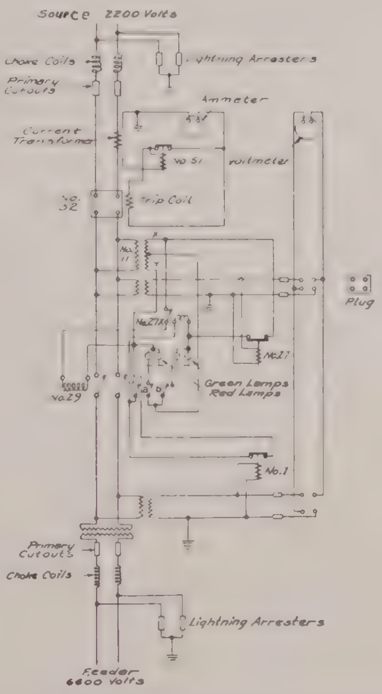


Fig. 5. Wiring Diagram of Standard Single-phase, Single-circuit Feeder Station

Oil circuit breaker *No. 52* affords a means of connecting or disconnecting the station manually, or automatically on overload.

A-c. under-voltage relay *No. 27* is designed to drop out at a voltage below which the signaling devices would not operate properly, and to pick up at a voltage slightly below normal operating voltage.

Auxiliary contactor *No. 27X* is introduced to relieve the contacts of relays *No. 27* and *No. 1* from carrying the coil current of contactor *No. 29*.

Master element relay *No. 1* is designed to pick up somewhere around normal operating voltage and to drop out at a voltage considerably below one-half normal. This relay is always energized when the transmission line is energized, and its particular function is to cause the idle station to be connected to the line when the line becomes de-energized and normal voltage exists at the incoming station.

The functioning of the station is as follows:

Assume the station shown in Fig. 5 connected to a 6600-volt transmission line that is energized from a duplicate station at the other end. Oil circuit breaker *No. 52* is normally closed, *No. 27* is energized and the green lamps are lighted, indicating that the station is in an operative condition. When the power fails in the other station relay *No. 1* is de-energized, completing the circuit of the coil of auxiliary contactor *No. 27X*, which in turn closes and energizes the coil of contactor *No. 29*, causing it to close and connect the station to the transmission line. This operation is practically instantaneous. The contacts of relay *No. 1* are bridged by one of the "a" interlocks and the other "a" interlock on contactor *No. 29* connects the red lights, while the opening of "b" interlock disconnects the green lights.

Should the voltage fail in this station the other station will immediately be placed

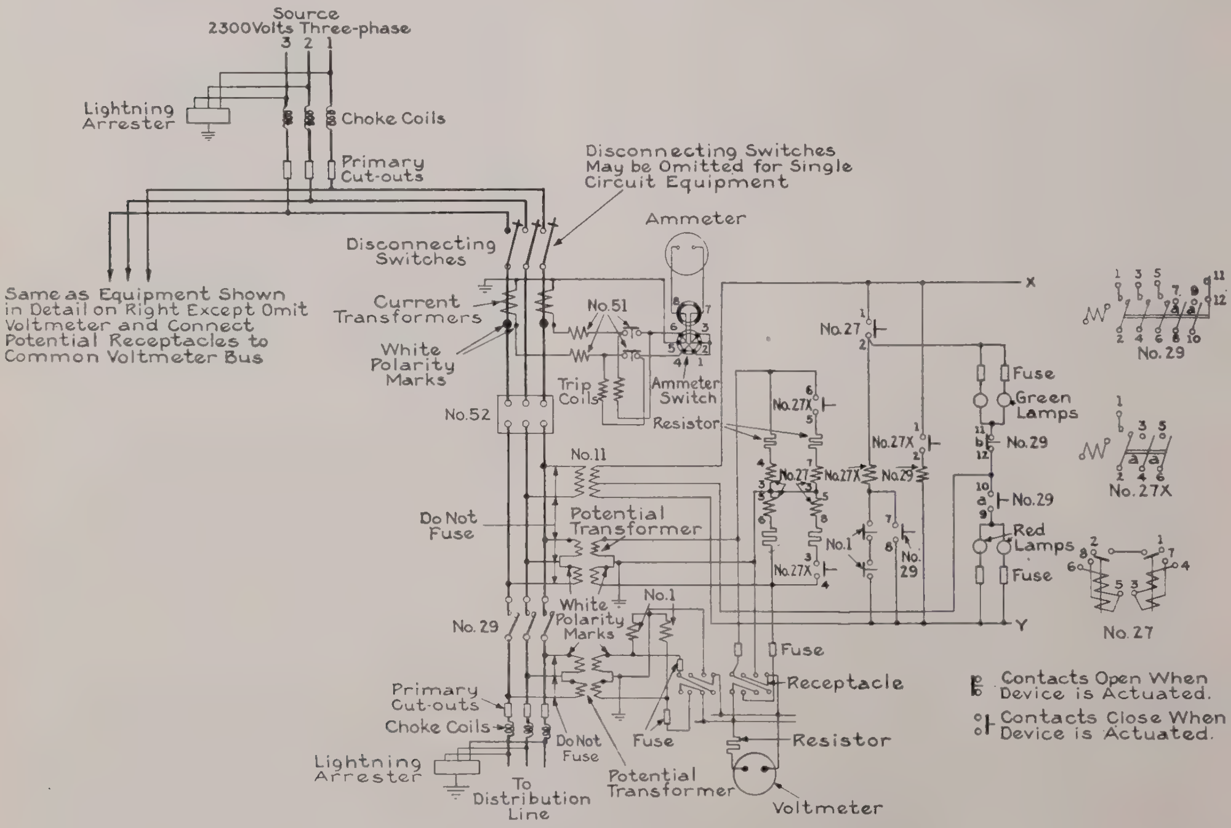


Fig. 6. Elementary Diagram of 3-phase, High-voltage Equipment

Control power transformer *No. 11* furnishes power for operating auxiliary contactor *No. 27X*, isolating contactor *No. 29* and the indicating lights.

Isolating contactor *No. 29* connects the station to the line when *No. 27* relay is energized and *No. 1* relay de-energized. When *No. 29* contactor closes, the contacts of *No. 1* relay are bridged by one of the "a" interlocks so that the contactor remains closed after *No. 1* relay has been re-energized. When *No. 27* relay is energized, the green lamps indicate that *No. 29* is open and the red lamps indicate that it is closed.

on the line in the manner above described, providing the voltage is satisfactory for the operation of the signaling device.

Should the transmission line be sectionalized, either intentionally or by accident, the reserve station will be connected to the line so that each portion of the sectionalized line will be energized from its adjacent station. However, before closing the sectionalizing switches or repairing a broken line, one of these stations must be disconnected.

If trouble occurs to cause a short circuit between line wires the operating station will be disconnected on switch *No. 52* by action of overload relay *No. 51* and this will cause contactor *No. 29* to open. The other station will immediately be connected to the line by reason of the low voltage condition, and if the short circuit persists, the station will be immediately disconnected in the manner described above; therefore, both stations will be disconnected until the fault is located and corrected, and the stations manually reconnected.

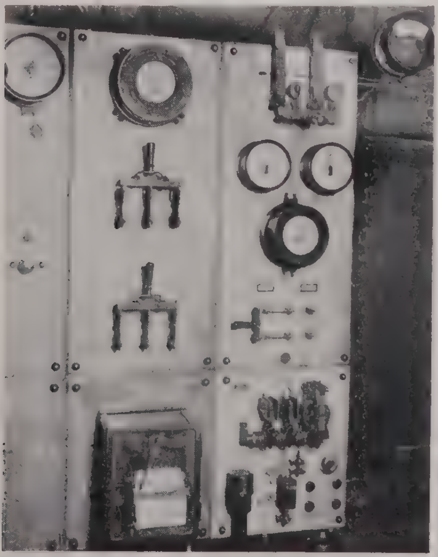


Fig. 7. Richmond, Fredericksburg & Potomac R.R. Manually-operated Feeder Panel in Richmond, Va., Station, Made Automatic by Addition of Automatic Switching Equipment on Sub-panel

If it is desired to shift the load from one station to the other, it is only necessary to open hand operated oil circuit breaker *No. 52* in the operating station, and then close it so that the station is in a condition to be switched on automatically if power fails at the other station.

An intermediate station feeds two adjacent line sections and is, therefore, a combination of two single feeder stations taking power from the same source; each feeder therefore functions independently with another station as above described.

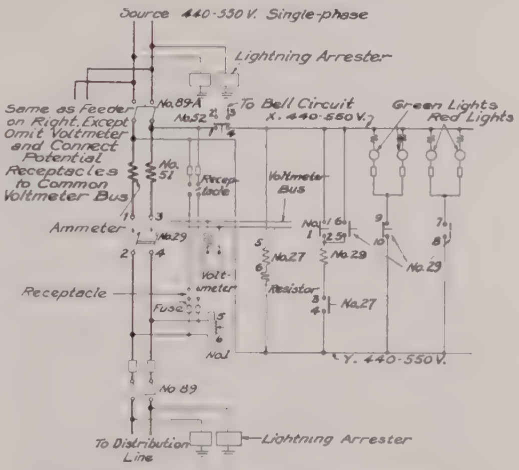


Fig. 8. Elementary Diagram of Single-phase, Low-voltage Station for Train Control

Three-phase delta stations operate in a manner similar to single-phase stations, the principal difference being that double the number of relays with their transformers connected to separate phases are required, and all main line equipment is three-pole. The control circuit for auxiliary contactor *No. 27X* is connected through the contacts of the two *No. 1* relays and those of the *No. 27* relay all in series. This insures that the station will not be connected to the line unless power is available on all three phases of the supply and a low voltage condition exists on all three phases of the transmission line; this prevents the station from being connected to the line unless the power is normal on all three phases and makes it impossible to connect two stations together in case one of the wires of the transmission line should be opened. Fig. 6 is an elementary diagram of a standard three-phase delta high voltage equipment. The circuits are arranged from left to right in order of sequence of operation. This means that the contacts and coil of a device are not necessarily shown together. By means of such a diagram it is easy to check the interrelations of the various pieces of equipment.

Three-phase Y stations are similar to three-phase delta stations, the only difference being that the relays with their operating transformers are required in all three phases.

Sometimes automatic switching equipments are located very close to the source of power, in which case it is permissible to omit the *No. 27* under-voltage relays because a single-phase or under-voltage condition will probably never exist.

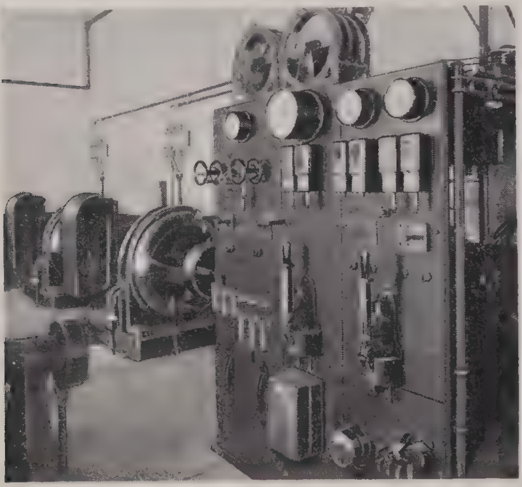


Fig. 9. Atchison, Topeka & Santa Fe Railway. Apparatus and automatic equipment for signaling and train control installed in power plant at Fort Madison, Iowa, Electric Co.

The first installation of automatic switching equipment for the supply of power to automatic block signals was made in 1918 by the Richmond, Fredericksburg & Potomac Railroad. The existing installation included a 6600-volt, 60-cycle transmission line from Richmond to Fredericksburg, Va., and from Fredericksburg to Potomac Yards (near Washington, D.C.). Manually operated 220-volt switchboards, one of which is illustrated in Fig. 7, located in the power houses at Richmond and Potomac Yards, supplied their respective line sections through step-up transformers. An emergency supply at Fredericksburg was likewise stepped-up from 220 volts but the switching was done on the 6600-volt side so that the line could be cut through if desired.

Owing to traffic delays resulting from power failures, automatic switching became a necessity and an arrangement that would make use of existing equipment as far as possible was decided upon. Sub-panels containing 220-volt automatic equipment were placed underneath the manually controlled panels in the Richmond and Potomac Yards stations, and a 220-volt double-circuit combined automatic and manual feeder panel was installed in a small concrete house at Fredericksburg.

The advent of automatic train control has greatly stimulated the demand for automatic substation equipment. Certain types of automatic train-control systems operate on alternating current. Continuity of power supply for train control is even more important than for an alternating current signaling system, because the de-energization of the train control devices for a certain time (approximately 5 seconds) will cause the application of the air brakes on the train.

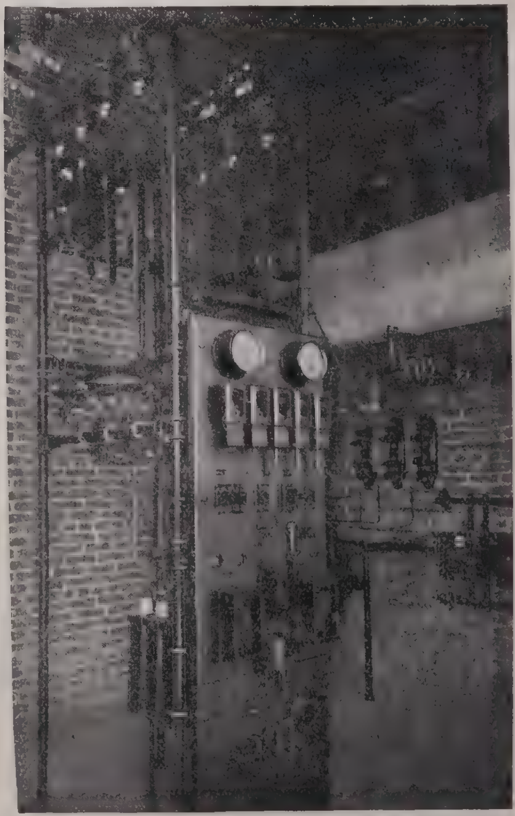


Fig. 10. Automatic Railway Signaling and Train Control Feeder Equipment in Chillicothe Station of the Atchison, Topeka & Santa Fe Railway

An a-c. train-control system may be installed in conjunction with an a-c. or a d-c. signaling system or where no signaling system is used. When installed with an a-c. signaling system, the automatic substation will be the same as described above. In other cases, owing to the very small amount of power required (only a few watts per track block), the transmission and automatic switching equipment may be low voltage. A number of 440- and 550-volt equipments have been installed and others are under construction. Fig. 8 is an elementary diagram of one of these low voltage stations. Air break equipment is used throughout for interrupting the circuit and the time-limit overload relay is connected directly in the coil circuit of relay *No. 29.* Aside from these modifications, the functioning of the equipment is identical with that of the high voltage stations.

A number of very interesting train control installations using automatic substations have been made during the past year and others are now under construction.

Atchison, Topeka & Santa Fe Railway Installation

This railway selected the Illinois Division for its first installation of automatic train control, between Fort Madison, Ia., and Corwith, Ill., a suburb of Chicago, a distance of 230 miles. All the traffic of the vast Santa Fe system to and from Chicago passes over this one stretch of track. This includes heavy suburban traffic moving at certain definite periods of the day and considerable freight traffic throughout the whole day. The uninterrupted movement of trains is, therefore, a very important matter and for this reason every precaution has been taken to insure continuity of service. Automatic substations have already been installed at Fort Madison, Galesburg, Chillicothe and Streator, and construction is under way for one station at Corwith and two at Joliet. Figs. 9 to 12 show various parts of this installation. The station at Corwith and the one at South Joliet are of the outdoor type, the switching equipments being installed in steel houses. The Corwith, Joliet and Fort Madison stations are single-feeder type and the other three are double-feeder type.

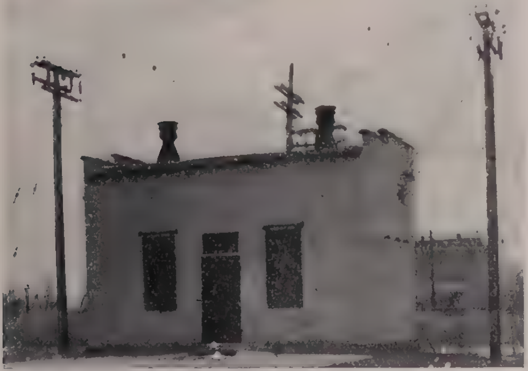


Fig. 11. Automatic Substation for Signaling and Train Control, Atchison, Topeka & Santa Fe Railway, Chillicothe, Ill.

All of the indoor stations followed standard arrangements with slight modifications necessary to meet local requirements. The switching equipment is so arranged that transmission line losses due to excitation of power transformers is reduced to a minimum.

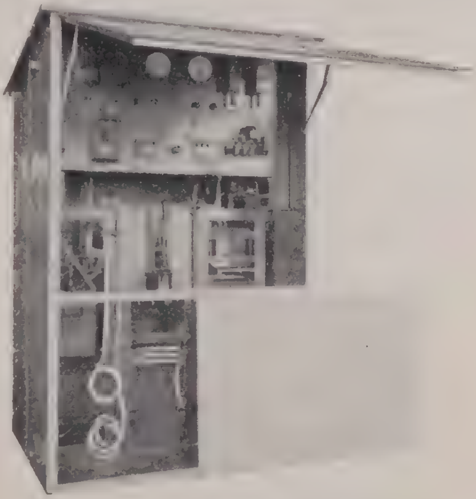


Fig. 12. Automatic Switching Equipment, Atchison, Topeka & Santa Fe Railway for Corinth and South Joliet (Ill.) Stations

All stations are 60-cycle, 3-phase, the transmission between Fort Madison and Chillicothe being at 4400 volts, and from Chillicothe to Corwith 6600 volts. Fort Madison station, illustrated herewith, receives power from the Keokuk system at 25 cycles and two frequency converters are installed to supply the 60-cycle system. Since this station normally feeds the line section to Galesburg, the control for these converters is manual. This is permissible because an operator is located in the station.

Reading Company Installation

During the summer months the traffic between Philadelphia and Atlantic City is exceedingly heavy and this requires a large number of high-speed trains operating under close headway; on this account absolute reliability of signals and train control equipments is essential. Automatic substations have been installed at Camden, Hammonton, and Atlantic City, N. J., a distance of 55 miles (see Figs. 13 and 14). Graphic meters installed in each station give a continuous record of the variation in voltage throughout the day.

Louisville & Nashville Railroad Installation

The first train-control installation on the Louisville & Nashville Railroad was made last year between Etowah and Madisonville, Tenn., a distance of 18 miles. This was the first installation using a 440-volt transmission line. Both stations are supplied with power from the Tennessee Power Company's system over different feeders. To insure continuity of service in case of simultaneous failure of power at both stations, a three-unit emergency motor-generator set was installed at Etowah, where 220 volts d-c. is obtained from the railroad shops. The third unit on the set is a 32-volt d-c. machine which is automatically connected to a storage battery in case the 220-volt d-c.

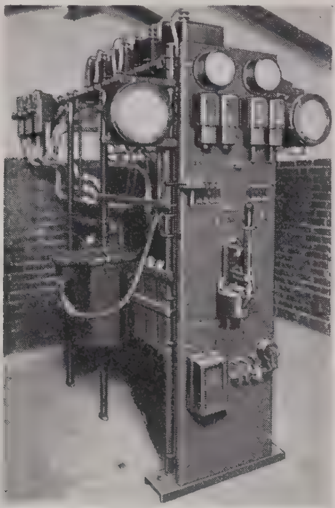


Fig. 13. Interior Automatic Substation for Signaling and Train Control, Installed on the Reading at Atlantic City, N. J.

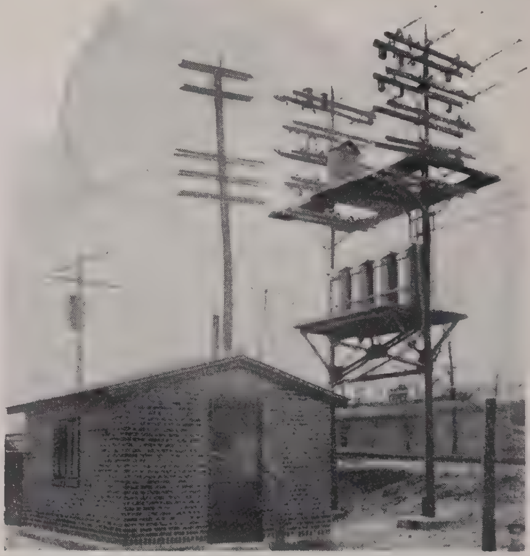


Fig. 14. Exterior Automatic Substation for Signaling and Train Control Installed on the Reading at Hammonton, N. J.

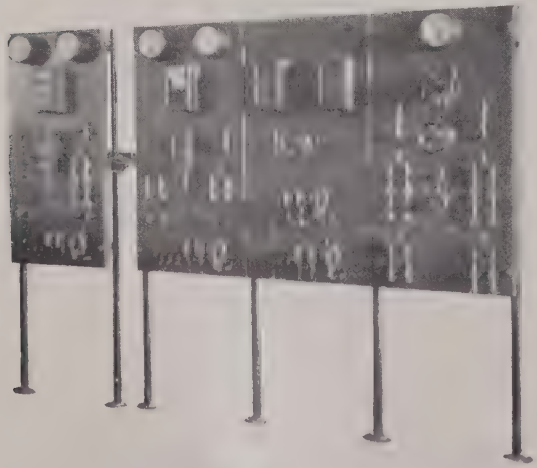


Fig. 15. Automatic Switching Equipment, Louisville & Nashville R.R. Co., Etowah and Madisonville (Tenn.) Stations

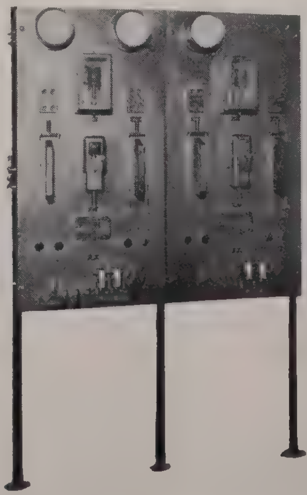


Fig. 16. Automatic Switching Equipment for Train Control, Illinois Central R.R. Champaign, Ill.

is not available when the a-c. supply fails. The 32-volt machine is also used to charge the battery. The control is so arranged that in case a power failure occurs while the battery is being charged, the set will automatically take up the a-c. load. Fig. 15 illustrates the single-panel switchboard at Madisonville, and the three-panel switchboard at Etowah. One panel of the latter is a duplicate of the switchboard at Madisonville and the other two panels control the motor-generator set illustrated in Fig. 17.

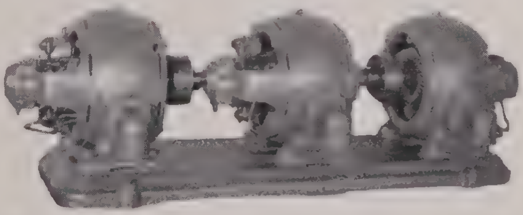


Fig. 17. Motor-generator Set for Emergency Power Supply for Train Control System Louisville & Nashville R.R. Co., Etowah, Tenn.

The system is being extended north to Corbin, a distance of 144 miles, making the total length of train control territory 162 miles. Five additional automatic substations are under construction and transmission will be at 550 volts.

Illinois Central Railroad Installation

The first installation of automatic train control on the Illinois Central Railroad (see Fig. 16) is being made between Champaign and Branch Junction, Illinois, a distance of 122 miles, but at present only the trial installation of 22 miles between Champaign and Tuscola is in service. The transmission is at 550 volts.

Delaware, Lackawanna & Western Railroad Installation

The train-control installation on the Delaware, Lackawanna & Western Railroad is between Elmira and East Buffalo, N.Y., a distance of 141 miles. The transmission is at 550 volts. Single feeder stations are located at East Buffalo and Elmira, and double feeder stations at East Bethany, Dansville and Bath. The power supply at Dansville, Bath and Elmira is 60-cycle, 2300 volts which is stepped down to 575 volts, but on account of the unsteady voltage at these three points small capacity automatic voltage regulators are being furnished. The power supply at East Buffalo and East Bethany is 25-cycle, 4600 volts; this is transformed to 110 volts, and 1.5 kv-a, 110-volt frequency converters are installed in duplicate at each station with automatic starting equipment. The generated voltage is stepped up to 550 volts. These are novel installations in that they are the first ones requiring automatic voltage regulators and automatic frequency changers of such small capacity.

The Theory and Design of Ballast Resistors

By H. A. JONES

RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

In our May issue we published an article by Mr. Jones entitled "The Ballast Resistor in Practice," which was in a way preliminary to the present article. Since the constant current action of the iron filament in hydrogen seemed not widely understood, it appeared best to give the more general story first, outlining the various applications of the ballast resistor, and to reserve for a subsequent issue the theoretical considerations of constant current action. Below we are presenting the mathematical discussion of the subject, which Mr. Jones has worked out.—EDITOR.

It has been shown(1) that the volt-ampere characteristic curve for an iron wire resistance operating in hydrogen will exhibit "ballast action" (i.e., the current will remain constant over a wide range of voltage), if the total heat loss in watts (W) from the resistance increases proportionately slower with the absolute temperature than the resistance (R).

Since W, the total heat loss in watts from a filament operating in a gas, and R, the resistance of the filament at the operating temperature, are both functions of the temperature, over any small interval of temperature, we may write:

$$W = AT^{n_W} \tag{1}$$

and

$$R = BT^{n_R} \tag{2}$$

Here n_W and n_R are the exponents of the absolute temperature with which W and R increase with the absolute temperature.

Equations (1) and (2) may be written

$$n_W = \frac{d \log W}{d \log T} = \frac{T\, dW}{W\, dT} \tag{3}$$

and

$$n_R = \frac{d \log R}{d \log T} = \frac{T\, dR}{R\, dT} \tag{4}$$

As already pointed out, ballasting will occur with an iron wire in hydrogen when

$$n_W - n_R < 0. \tag{5}$$

Hence, if n_W and n_R are plotted as functions of temperature, the n_W curve will lie below the n_R curve in the temperature region in which equation (5) is satisfied, i. e., from such a plot we can obtain the filament temperature range in which ballasting will occur.

The n_R curve for iron has been derived from A. A. Somerville's(2) measurements on the temperature coefficient of resistance of iron and is plotted in Fig. 1.

The calculation of the total heat losses from a filament operating in hydrogen gas will now be considered in detail. The total heat losses in watts, W, will then be used to derive the n_W curves for various pressures of hydrogen. The method used in designing ballast resistances on the basis of the n_W and n_R curves plotted as functions of temperature will be pointed out.

Radiation Losses from a Filament

The watts lost by radiation may be calculated from the Stefan-Boltzmann equation:

$$W_r = E\sigma\,(T_2^4 - T_1^4)\,A \tag{6}$$

where E is the total emissive power of the metal at the temperature T_2, and

T_1 = temperature of the room.

A = area of the radiating surface.

σ = constant = 5.709×10^{-12} watts cm.$^{-2}$, sec.$^{-1}$, deg.$^{-4}$.

It is very difficult to obtain accurate measurements of the total emissive power, E, of a metal at low temperatures. Foote(3) has extended the Aschkinass(4) derivation of the total radiating power of a metal in terms of its volume resistivity and finds that his formula agrees well with the experimental data on platinum.

Foote's formula is

$$E = 0.5736\sqrt{rT} - 0.1769\, rT \tag{7}$$

where r is the volume resistivity of the radiating metal in ohm cm. at the absolute temperature T.

At 1050 deg. K., $r = 125.5 \times 10^{-4}$, whence $E = 0.185$, which value as pointed out by Davisson and Weekes(5) should be corrected for the deviation from Lambert's Cosine Law. This correction amounts to 13 per cent at 1050 deg. K., whence $E = 0.209$.

Hence, if we assume $T_2 = 1050$ deg. K., and $T_1 = 293$ deg. K. from equation (6), we obtain

$$W_r = 1.48 \text{ watts cm}^{-2}$$

The heat loss due to radiation is only of importance at high filament temperatures and very low gas pressures. In the case of the ballast resistance where we have a fairly high pressure of hydrogen (10 cm. or more) and the temperature of the filament is only moderately high (1073 deg. K, at maximum), the heat loss due to conduction by the gas is easily the predominant factor, for as will be shown in a subsequent section of this article the actual observed heat loss from an iron wire in hydrogen under ballasting conditions amounts to approximately 100 watts per cm.^{2}

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(1) H. A. Jones, G. E. REVIEW, May, 1925.

(2) A. A. Somerville, *Phys. Rev.*, 31, 261 (1910).

(3) Foote: "*Bull. of Bur. of Stds.*, 607 (1915).

(4) E. Aschkinass: *Ann der Phys.*, 17, 960 (1915).

(5) *Journal of the Opt. Soc. of Amer.*, Vol. 8, No. 5, May, 1924.

Conduction Losses from a Filament in Hydrogen

The method adopted to calculate the heat loss by conduction has been developed by Dr. Langmuir(6) and subsequently greatly extended to a more general case by Mr. C. W. Rice.

Langmuir's Film Theory of Convection

Consider (Fig. 2) the case of a horizontal wire A of diameter d at a given temperature T in a gas, the wire being co-axial with the cylindrical container C.

The gas adjacent to the wire becomes heated and rises while cooler gas of greater density flows in to take its place. This movement or streaming motion in the gas continues to a point at which the critical velocity conditions in the gas no longer permit of simple streaming motion. The motion then becomes turbulent. Langmuir reasons that the discontinuity between stream line and turbulent motion marks the outer edge of a film of gas of diameter b through which the heat transfer from the wire takes place. In this film the inner boundary has the temperature of the wire while the outer boundary has the temperature of the ambient gas. For purposes of calculation Langmuir assumes the film to be a cylinder concentric with the wire and relatively stagnant. By this reasoning and simplification, the problem of free convection is reduced to a problem of conduction in the steady state.

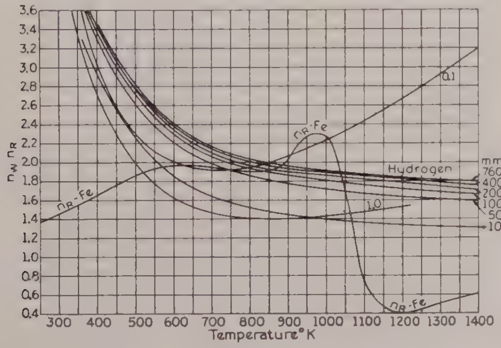

Fig. 1. Flot of n_W for Hydrogen (at various pressures) and n_R for Iron as Functions of Temperature

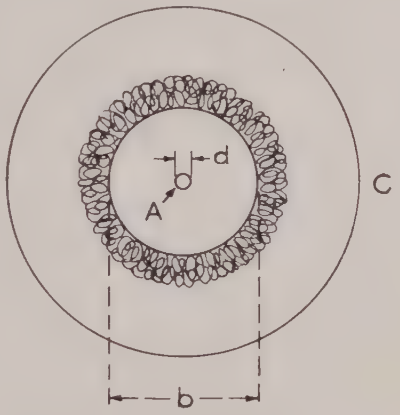

Fig. 2. Film Around a Hot Wire in a Gas

Langmuir shows that when this steady state is reached, the heat losses by convection may be accurately expressed by

$$W_c = S \int_{T_1}^{T_2} k dt \tag{8}$$

where W_c is the watts lost from a wire at temperature T_2 to the ambient gas at temperature T_1. The value k is the heat conductivity of the gas and S is a "shape factor," the value of which is determined by the geometry of the body and the positions of the surfaces by which the heat leaves and enters the body.

Langmuir developed the film theory of conduction in the following manner:(7)

> In any problem in heat conduction where constant conditions prevail we may write
>
> $$\frac{dq}{ds} = \frac{k\, dT}{dX} \tag{9}$$
>
> where dq is the heat flowing per second through the area ds; k = heat conductivity of the gas, dT = temperature drop and X is a distance measured perpendicular to the surface ds.

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(6) Langmuir: *Trans. Amer, Electrochem, Soc.*, *20*, 335 (1911).
" *Phys. Rev.*, 34, 6, 401 (1912).
" *A. I. E. E.*, Vol. 31, Part I, 1229 (1912).
" *J. A. C. S. 34*, 860, (1912).
" *Trans. Amer. Electrochem. Soc. 23*, 299 (1913).
" *A. I. E. E. 32*, Part I, 301 (1913).
Langmuir & Mackay: *J. A. C. S. 36*, 8, 1708 (1914)
Langmuir: *J. A. C. S. 37*, 3, 417 (1915).
" *J. A. C. S. 38*, 6, 1145 (1916).

(7) I. Langmuir· *Phys. Rev. 34*, 6, 401 (1912).

If the heat flux is uniform over the entire surface s, we may separate the variables and integrate the equation as follows:

$$\int kdT = q\int \frac{dX}{s} \tag{9a}$$

where k is a function of T alone, and s is a function of X alone.

Stating the rate of heat loss in watts (W), we have:

$$W = \frac{4.19\int kdT}{\int \frac{dX}{s}} \tag{9b}$$

Consider a wire of diameter d surrounded by a cylindrical film of gas of diameter b. Let T_2 be the temperature of the wire and T_1 the temperature of the gas at the outer surface of the film, i.e., at a distance $b/2$ from the center of the wire. Then if l is the length of the wire

$$\int \frac{dX}{s} = \frac{1}{2\pi l}\log_e \frac{b}{d} \tag{9c}$$

If W is the energy in watts conducted away from the wire per unit of length, then

$$W_c = \frac{4.19\times 2\pi}{\log_e \frac{b}{d}}\int_{T_1}^{T_2} kdt \tag{10}$$

For convenience we will write

$$\phi = 4.19\int_0^T kdt \tag{10a}$$

and place

$$S = \frac{2\pi}{\log_e \frac{b}{d}} \tag{10b}$$

whence

$$W_c = S\ (\phi_2 - \phi_1). \tag{11}$$

The value of S for a single wire co-axial with a cylindrical glass container is

$$S = \frac{2\pi l}{\log_e b/d} \tag{12}$$

where b is the diameter of the film of gas around the wire through which conduction takes place, and d is the diameter of the wire of length l.

Calculation of Thermal Conduction, ϕ

To calculate the function ϕ for different absolute temperatures, it is necessary to express the heat conductivity k as a function of the absolute temperature.

However, experimental data available on the heat conductivity of gases as a function of temperature are rather meager, so that Langmuir has calculated the heat conductivity for the different gases studied from the following relations derived from the kinetic theory of gases(8)

$$k = Muc_v \tag{13}$$

where k = heat conductivity, M is a constant for a gas, u = viscosity and c_v is the specific heat per gm. at constant volume.

Langmuir(9) uses the value of M deduced by Eucken, who showed that this constant is 1.90 for hydrogen, and also that this value is independent of the temperature over a wide range.

The variation of the viscosity of the gas with temperature has been determined by Sutherland's(10) relation which may be written

$$u = \frac{KT^{1/2}}{1+\frac{c}{T}} \tag{14}$$

in which, for hydrogen,

$$K = 6.6\times 10^{-6}$$

and $c = 77$(11)

For the specific heat of hydrogen, Langmuir chose Pier's data, according to which

$$c_v = F\ (1+\alpha T) \tag{15}$$

where $F = 2.21$
and $\alpha = 0.0002$

Substituting these values for u and c_v we may write

$$k = MF\ (1+\alpha T)\frac{KT^{1/2}}{1+\frac{c}{T}} \text{ cal. sec.}^{-1}\text{ cm.}^{-1}\text{deg.}^{-1} \tag{16}$$

Substituting A for 4.19 M F K to convert to watts we obtain

$$k = A\ (1+\alpha T)\frac{T^{1/2}}{1+\frac{c}{T}} \text{ watts cm.}^{-1}\text{ deg.}^{-1} \tag{16a}$$

To evaluate ϕ as a function of temperature we may write

$$\phi = \int_0^T kdT = A\int_0^T \left((1+\alpha T)\frac{T^{1/2}}{1+\frac{c}{T}} \right) dt \tag{16b}$$

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(8) Meyer: "Kinetic Theory of Gases."
(9) *Phys. Rev.* *34*, 6, 401 (1912).
(10) *Phil. Mag.* *36*, 507 (1893).
(11) Fisher: *Phys. Rev.* *24*, 385 (1907).

and since α is negligible except for very large values of T we have as a very close approximation

$$\phi = A\ (1+0.6\,\alpha T)\int_0^T \frac{T^{1/2}\,dT}{1+\frac{c}{T}} \tag{16c}$$

From this we obtain

$$\phi = A\ (1+0.6\alpha T)\left(2/3\ T^{3/2} - 2cT^{1/2} + 2c^{3/2}\tan^{-1}\sqrt{\frac{T}{c}}\right) \tag{17}$$

The values of ϕ for hydrogen calculated by Langmuir, using this equation, are plotted in Fig. 3.

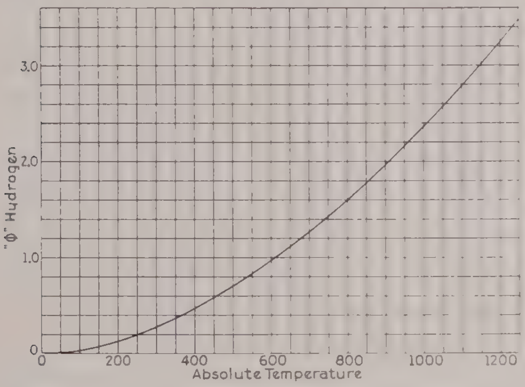

Fig. 3. Plot of the Thermal Conduction in Hydrogen, ϕ as a Function of Temperature

Langmuir found that this simple assumption of a film theory enabled him to obtain excellent agreement with his experiments made on small wires over wide ranges in temperature and pressure in different gases. He found that the film thickness in a given gas was independent of the temperature of the wire and merely depended upon the ambient temperature and pressure.

E. Q. Adams and Langmuir have developed the following relation to connect the film diameter with the wire diameter:

$$\log_e \frac{b}{d} = \frac{2B}{b} \tag{18}$$

where b = outer diameter of film in cm.

d = wire diameter in cm.

B = the film thickness in cm. for a plane surface in the same gas having the same ambient temperature and pressure. For air at 20 deg. C. and 76 cm. Hg, $B = 0.43$ cm.(12)

As a result of an extensive series of experiments, Langmuir concludes that the thickness B of the plane film varies directly as the viscosity and inversely as the density of the gas. Whether the changes in density were due to changes in temperature or pressure, or even to the substitution of a gas of different chemical composition, seemed to have little effect on the validity of this rule.

Let us consider a specific case to demonstrate the usefulness of Langmuir's theory. Assume a wire infinitely long (to be free from end corrections) suspended co-axially in a horizontal cylinder of infinite diameter. The wire diameter we shall assume to be 8.9×10^{-3} cm. Taking 0.43 cm.(13) as the plane surface value of B for air at 293 deg. K, and 760 mm. Hg, it can be shown from density considerations that B for hydrogen at 293 deg. K and 20 cm. pressure is 45.3 cm. Substituting this value in equation (18) we obtain $b = 12.4$ cm. This value, when substituted in equation (12) gives for the shape factor per cm. length of filament, $S_1 = 0.869$.

From Fig. 3:

ϕ_{H2} at 1050 deg. K = 1.57 watts/cm.

ϕ_{H2} at 293 deg. K = .26 watts/cm.

Substituting these values for S_1, ϕ_2 and ϕ_1 in equation (11) we obtain

$W_c = 2.01$ watts conducted per cm. length of filament.

C. W. Rice's Extension of Langmuir's Film Theory

By the method of dimensions, confirmed by many experiments on large and small bodies at both high and low temperatures, C. W. Rice(14) has derived the following general equation for the effective film thickness for free convection

$$B = K\,d\left(\frac{k}{h\,c_p}\right)^m \left[\frac{\gamma}{(\alpha\,g\,\Delta\,t)^{1/2}\,d^{3/2}}\right]^n \text{cm.} \tag{19}$$

where K = experimental constant depending on the system of similar bodies under consideration.

d = characteristic linear dimension of body in cm.

k = heat conductivity at average temperature $T_{(a)}$ in watts cm.$^{-1}$ deg.$^{-1}$.

h = viscosity of fluid at $T_{(a)}$ cm.$^{-1}$ (gm. sec.)$^{-1}$.

c_p = specific heat at constant pressure for average temperature $T_{(a)}$ in joules gm.$^{-1}$ deg.$^{-1}$.

m = experimental exponent.

γ = h/p = kinematic viscosity of fluid for average temperature, in sq. cm. sec.$^{-1}$.

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(12) Langmuir: *Trans. Amer. Electrochem, Soc.* *23*, 299 (1913).

(13) Langmuir, *Phys. Rev.*, 1911, loc. cit.

(14) C. W. Rice, *Trans. A.I.E.E.*, June 1923, also Feb. 1924.

ρ = density of fluid in gms. cc.$^{-1}$
α = coefficient of density change per deg. C. for average temperature in deg. C. For ideal gases $\alpha = \frac{1}{273}$.
T_a = average temp. in deg. C. $= \frac{T_2+T_1}{2}$.
g = acceleration of gravity = 980.6 dynes per cm².
Δt = difference between surface and ambient temperatures in deg. C.
n = experimental exponent for the system of similar bodies under consideration.

When dealing with ideal gases the first factor, $(k/hc_p)^m$ in equation (19), can be neglected since its value is nearly unity and since this value does not vary greatly from one gas to another. Under these conditions, the effective film thickness may be written

$$B = k_1\, d \left[\frac{\gamma}{(\alpha g\, \Delta\, t)^{1/2}\, d^{3/2}}\right]^n \text{cm.} \qquad (19a)$$

The free convection from a long horizontal cylinder in *gases* and *liquids* is given by Rice's equation:

$$W_c = \frac{2\,\pi\, l\, \Delta\,\phi}{\log_e \left(\frac{2B+d}{d}\right)} \text{ watts.} \qquad (20)$$

where l = length of cylinder in cm.
$\Delta\phi$ = thermal conduction in watts per cm. $= \phi_{T_2} - \phi_{T_1}$
d = diameter of cylinder in cm.
B = film thickness in cm. from equation (19).

Experimentally, $m = 0.25$, $n = 0.54$ and $K = 2.60$ for either gases or liquids in the case of horizontal cylinders.

Rice's equation has been checked from experimental data in gases at fairly high pressures. At these pressures, the temperature drop between a hot wire and the ambient gas is negligible. This is not true, however, at lower pressures, as pointed out by Smoluchowski(15) who introduces a temperature drop coefficient which is of the order of magnitude of the mean free path of the gas molecules to which it is proportional and hence inversely proportional to the pressure.

For this case, Smoluchowski writes

$$W_c = \frac{2\,\pi\, H\, l\, (T_1 - T_0)}{\log_e \frac{r_0}{r_1} + \gamma\left(\frac{1}{r_1} - \frac{1}{r_0}\right)} \qquad (21)$$

where H = thermal conductivity of the gas
l = length of the wire.
T_1 = temperature of the wire which is uniform over its entire length.
T_0 = temperature of the glass wall.
r_0 = radius of the glass cylinder.
r_1 = radius of the wire.
γ is the coefficient which corrects for the temperature drop between the hot wire and the ambient gas.

Since γ is proportional to the mean free path we may write

$$\gamma = \gamma_0\, L = \gamma_0\, L_0\, T$$

where γ_0 is the value of γ at 1 deg. K while L_0 is the mean free path of the gas molecules at pressure p and 1 deg. K.

$\gamma_0 = 5.7$ for hydrogen on silver(16)

$\gamma_0 = 5.6$ for hydrogen on platinum

according to measurements of Knudsen.(17)

However, since we use Rice's expression involving the wire *diameter* and the film *thickness* B, the correction term for the Smoluchowski temperature drop around the wire assumes the form:

$$2\,\gamma_0\, L_0\, T \left(\frac{1}{d} + \frac{1}{b}\right) \qquad (22)$$

where $b = 2\,B + d$.

Hence the equation, which we may use over the entire pressure range, becomes

$$W_c = \frac{2\,\pi\, l\, \Delta\,\phi}{\log_e \left(\frac{b}{d}\right) + 2\gamma_0 L_0 T \left(\frac{1}{d} + \frac{1}{b}\right)} \qquad (23)$$

Thus we observe that as the pressure is decreased, the correction term increases in value and W_c decreases. Similarly for large pressures, the correction term becomes negligible. Actually the term $\left(\frac{2\gamma_0 L_0 T}{b}\right)$ is found to be negligible at all pressures in hydrogen.

We may assume that the mean of the γ_0 values for hydrogen on silver and platinum will give a good approximation for the value of γ_0 for hydrogen on iron.

Hence for hydrogen on iron:

$$\frac{2\,\gamma_0\, L_0\, T}{d} = \frac{5.47 \times 10^{-4} \times T_{(a)}}{d \times p}$$

where $T_{(a)}$ = average temperature between the wire and the glass wall in deg. K.
d = diameter of the wire in cm.
p = pressure of hydrogen in mm. of Hg.

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(15) M. V. Smoluchowski—*Wied. Ann. 64*, 101 (1898).
(16) E. Gehrcke: *Ann d. Phys. 2*, 103 (1900).
(17) M. V. Smoluchowski: *Ann d. Phys.35*, 983 (1911).

If we use the data as previously used in Langmuir's equation (11), in equation (19), that is,

$T_2 = 1050$ deg. K.
$T_1 = 293$ deg. K.
$d = 8.9 \times 10^{-3}$ cm.
$p = 200$ mm. of hydrogen,

we obtain

$B = 0.601$ cm.

Substituting this value in equation (23) we obtain

$W_c = 2.834$ watts/cm. length.

The agreement between this value and that obtained from Langmuir's formula is good, considering the fact that loop filaments 5 to 8 cm. in length were used in Langmuir's experiments, rather than a single co-axial filament. It is well known that the effect of the heat conducted from one leg of the filament is to decrease the amount of heat conducted from the other leg.

It is of interest to note the empirical formulas derived by Busch(18) to express his experimentally observed heat losses by conduction in hydrogen.

$$W_c = \frac{T^{3/2} - T_0^{3/2}}{\dfrac{1300}{1 - e^{\frac{1.1 r_1}{L_0}}} + \dfrac{10.2\ T}{\dfrac{r_1}{L_0} + 1.4\left(1 - e^{-\frac{1.3\, r_1}{L_0}}\right)}} \tag{24}$$

is the expression which fits his data between 0.33 mm. and 250 mm. pressure. At pressures greater than 20 mm. Busch found the following formula to fit his experimental data on the heat lost by conduction in hydrogen:

$$W_c = \frac{T^{3/2} - T_0^{3/2}}{1300 + 10.2\ T_0 \dfrac{L_0\, T/T_0}{r_1 + 1.4\ L_0}} \tag{25}$$

In equations (24) and (25)

W_c = watts lost by conduction per unit length of filament.
T = temperature of the gas at a distance r from the axis of the wire.
T_0 = temperature of the glass walls.
r_1 = radius of the wire.
L_0 = mean free path of the gas molecules at 1 deg. K. and pressure p.
e = base of Naperian logs.

The Design of Ballast Resistances

We have seen from equation (5) that ballasting occurs with an iron wire in hydrogen gas when $n_W - n_R$ is equal to or less than zero.

The $n_{R(T)}$ curve for iron has been derived as mentioned previously and plotted in Fig. 1. The $n_{W(T)}$ curves for hydrogen are derived from the expression:

$$n_W = \frac{(W_c)\, n_{W_c} + (W_R)\, n_{W_R}}{W_c + W_R} \tag{26}$$

W_c = heat loss by conduction from equation (23).

$$n_{W_c} = \frac{T}{W}\frac{dW_c}{dT} = \frac{T\dfrac{d\phi}{dT}}{\Delta\phi} - \frac{\left(\dfrac{T}{b}\dfrac{db}{dT}\right) + \dfrac{2\,\gamma_0\, L_0\, T}{d}}{\log_e \dfrac{b}{d} + \dfrac{2\,\gamma_0\, L_0\, T}{d}} \tag{27}$$

W_R = heat loss by radiation from equation (6), where the total emissivity is corrected for the variation from Lambert's Cosine Law by the method of Davisson and Weekes.(5)

$$n_{W_R} = \frac{T\dfrac{dW_R}{dT}}{\Delta\, W_R} \tag{28}$$

The $n_{W(T)}$ curves were evaluated for constant density of hydrogen, since ordinarily a bulb is filled with gas at room temperature and at a pressure p which will increase when the bulb is sealed off and the filament is heated. The gas temperature has been assumed to be the average temperature of the wire and the glass wall. The wall temperature has been assumed to be 293 deg. K in each case.

In equation (23), $b = 2\ B + d$ and B is calculated from equation (19). For hydrogen, this equation may be simplified to:

$$B = 0.477\ p^{-0.54}\ d^{0.19}\left[\frac{(T + T_0)^{5/2}}{154 + T + T_0\sqrt{T - T_0}}\right]^{0.54} \text{cm. (19b}$$

where p = pressure of hydrogen in mm. of mercury.
d = diameter of the wire in cm.
T = temperature of the wire in deg. K.
T_0 = temperature of the wall in deg. K.

For wires less than 0.254 cm. in diameter, n_W is independent of the wire diameter and is a function of the temperature and the pressure. Hence from the plots of $n_{W(T)}$ and $n_{R(T)}$ in Fig. 1, we may calculate the range of ballast action in volts for any diameter of iron wire in all pressures of hydrogen gas for which n_W is known and found to satisfy the expression $n_W - n_R < 0$.

For example, let us calculate the voltage range for ballast action for iron wires of different diameters each suspended coaxially in a cylindrical glass tube of infinite diameter sealed off and containing hydrogen at 100 mm. pressure at room temperature (293 deg. K).

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(18) Busch: *Ann. d. Phys. 64*, 401 (1921).

Since the $n_{W(T)}$ curve for hydrogen at 100 mm. pressure and the $n_{R(T)}$ curve for iron show that ballasting will obtain between 840 deg. K. and 1045 deg. K., we may calculate the filament temperature range 1045 to 840 deg. in volts per cm. length for iron filaments of different diameters. The results of such a calculation based on the above assumptions are given in Table I.

TABLE I

840 DEG. K.

1	2	3	4	5	6	7	8	9	10	11	12
d	B_1	b_1	$\log_e \frac{b_1}{d}$	$\frac{2\,\gamma_0 L_0 T_1}{d}$	$\log_e \frac{b_1}{d} + 2\,\gamma_0 L_0 T/d$	W_{C_1}/cm.	W_{R_1}/cm.	$W_{C_1}+W_{R_1}$	R_1/cm.	I_1	V_1/cm.
.00254	.453	.909	5.86	.939	6.799	1.359	.00317	1.362	14.72	.3042	4.478
.0254	.702	1.429	4.025	.0939	4.119	2.248	.0317	2.280	.1472	3.935	.579
.127	.953	2.033	2.772	.0188	2.791	3.31	.1587	3.469	.005888	24.26	.1428
.254	1.086	2.426	2.265	.0094	2.274	4.065	.3174	4.382	.001472	54.6	.0803

1045 DEG. K.

1	2	3	4	5	6	7	8	9	10	11	12	13
d	B_2	b_2	$\log_e \frac{b_2}{d}$	$\frac{2\,\gamma_0 L_0 T_2}{d}$	$\log_e \frac{b_2}{d} + 2\,\gamma_0 L_0 T/d$	W_{C_2}/cm.	W_{R_2}/cm.	$W_{C_2}+W_{R_2}$	R_2/cm.	I_2	V_2/cm.	$V_2 - V_1 = V_L$/cm.
.00254	.438	.879	5.85	.988	6.838	2.1	.01066	2.111	23.3	.301	7.01	2.532
.0254	.678	1.381	4.0	.0988	4.099	3.5	.1066	3.607	.233	3.935	.917	.338
.127	.921	1.969	2.74	.0198	2.76	5.19	.533	5.723	.00932	24.76	.2305	.0877
.254	1.05	2.354	2.25	.0099	2.26	6.35	1.066	7.416	.00233	56.4	.1314	.0511

(1) d = diameter of the wire in cm.
(2) B = film thickness in cm. from equation (16).
(3) $b = 2\,B + d$.
(5) $\frac{2\,\gamma_0 L_0 T}{d}$ = coefficient which corrects for temperature drop around the wire.
(7) W_c = watts loss by conduction per cm. length of wire from equation (23).
(8) W_r = watts loss by radiation per cm. length of wire from equation (6).
(10) R = resistance of 1 cm. length of wire at these temperatures.
(11) I = current necessary to maintain the wire at these temperatures.
(12) V = voltage drop per cm. length of wire at these temperatures.
(13) V_L = voltage drop per cm. length of wire in passing through the entire ballast range.

Column 13, Table I, gives V_L, which expresses the length of the ballasting range in volts per cm. length of the filament.

These values are found to fit the equation:

$$V_L = K\,d^{-0.878} \qquad (29)$$

or

$$V_L = 2.532\,d^{-0.878}\ (d \text{ in mils}) \qquad (30)$$

Similarly, the starting voltage for ballast action in volts per cm. length of filament may be expressed as:

$$V_S = 4.478\,d^{\,0.8884} \qquad (31)$$

or

$$\frac{V_L}{V_S} = 0.57\,d^{\,0.0104} \qquad (32)$$

For a filament of l cm. length, we may write:

$$\log V - \log K + 0.878 \log d - \log l = 0 \qquad (33)$$

It was pointed out by Mr. W. G. Baker that since

$$f(V_L) + \phi(d) + \Psi(l) = 0,$$

it is possible to represent this equation by three scales so arranged that corresponding values of the functions are represented by co-linear points. Further, since $I = f_1(d)$ and V_s is a function very similar to V_L, it is possible to plot these functions beside d and V_L respectively using a slightly different scale.

Such a nomogram based on the above calculations is shown in Fig. 4. To illustrate the use of the nomogram, suppose we wish to know the length and diameter of iron wire to be suspended coaxially in a horizontal glass cylinder in order that we may obtain a constant current of 1 amp. over a range of 10 volts. From Scale *1* we see that one amp. is the ballast value of current for an iron wire 2.91 mils in diameter. By placing a straight edge through this point and the point corresponding to ten volts on the left side of Scale *2*, we read off 10 cm., total length of filament for this case, on Scale *3*. From the right side of Scale *2*, we also note that V_s, the starting voltage for ballast action, is 17.35 for this case. Hence a lamp having a single coaxial filament of iron wire 2.91 mils in diameter and 10 cm. in length would ballast at 1 amp. between 17.35 and 27.35 volts.

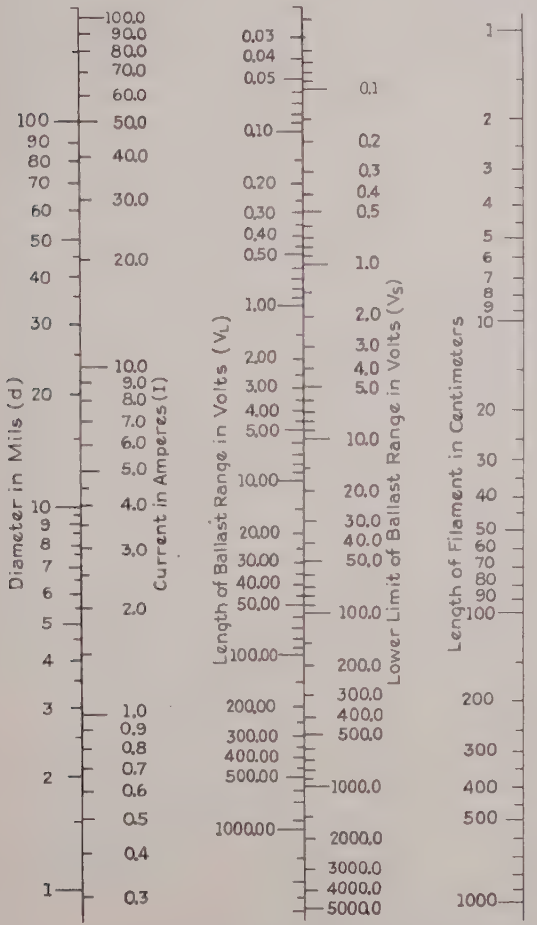

Fig. 4. Nomogram for Use in Designing Single Co-axial Filament Ballast Resistors When the Initial Pressure of Hydrogen is 100 mm.

In practice, the starting voltage for ballast action is commonly more important than the actual length of the ballast range. To illustrate this case, we may design a lamp to begin ballasting at 2 amp. and 20 volts. From Scale *1*, we observe that 5.5-mil. iron wire would be used. Placing a straight edge through this point on Scale *1* and the 20-volt point on the right side of Scale *2*, we read off 21 cm. total length of filament from Scale *3*. We observe also that 11.6 volts is the value of the function V_L on the left side of Scale *2* coincident with the value 20 volts of the function V_s on the right side of this scale. Therefore this lamp would ballast at 2 amps. between 20 and 31.6 volts.

From the intercepts of the $n_{W_{(T)}}$ curves at different pressures with the $n_{R_{(T)}}$ curve for iron, we note that the filament temperature range for ballast action varies with the pressure, though not in a regular manner. Obviously other nomograms could be constructed for these cases.

The Looped Wire Problem

However, due to practical difficulties, a wire coaxial with a cylinder is seldom used but rather *a looped wire* having several equal lengths is arranged symmetrically with respect to the axis of the glass cylinder. In this case, an extension of a theory treated by J. H. Jeans [(19)] allows us to evaluate the heat loss by conduction per unit length of wire when the wire has been looped into any number of equal lengths (n) symmetrically placed with respect to the axis of a cylinder.

Consider a wire of radius r_0, co-axial with a cylindrical container of radius a. Let E represent the field strength per unit length of the wire.

From Gauss' Theorem we have the relation

$$E=\frac{dV}{dr}=-\frac{2e}{r_1} \qquad (34)$$

where r_1 is the distance between a wire of infinite length and charge $+e$ per unit length, and any point in space.

By integrating we obtain

$$V=-2e\log_e r_1+C \qquad (34a)$$

where C is an integration constant which depends on the boundary conditions for evaluation. In the case of the cylindrical container which we are considering we set $V=0$, at $r_1=a$, so that

$$C=2e\log_e a. \qquad (34b)$$

Hence V, the potential at the surface of a single co-axial wire of radius r_0, becomes

$$V=2e\log_e\frac{a}{r_0} \qquad (35)$$

when the boundary condition is so chosen that $V=0$ at $r_1=a$.

Similarly let us consider two wires of equal radius r_0, symmetrically placed with respect to the axis of a cylinder of radius a, so that if r_1 is the distance between either wire axis and the cylinder axis, $2r_1$ represents the distance between wire axes. Let E_1 represent the field strength per unit length of *either* wire when two are present as postulated and r_2 be the distance between the axis of either wire whose charge is $+e_1$ per unit length and the axis of its imaginary electrical image of charge $(-e_1)$ per unit length.

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(19) J. H. Jeans: "Math. Theory of Electricity and Magnetism," *Cambridge Univ. Press* (1911), page 195.

It may be shown for this case by the method of electrical images that when r_1 *is large compared to* r_0,

$$V_1 = 2e_1 \log_e \frac{r_2^2 - r_1^2}{2r_1 \times r_0} \tag{36}$$

represents the potential at any point, r_1, (i.e., at either wire surface) when two such wires, each having a charge $+e_1$ per unit length, are placed symmetrically with respect to the axis of a cylinder of radius a, and each wire axis is a distance r_1 from the cylinder axis whose surface potential has been postulated equal to zero.

From Maxwell's Theorem we have

$$r_2 \times r_1 = a^2 \tag{37}$$

Substituting $\frac{a^2}{r_1} = r_2$ in the above equation we obtain,

$$V_1 = 2e_1 \log_e \frac{\left(\frac{a^2}{r_1}\right)^2 - r_1^2}{2r_1 r_0} \tag{38}$$

We have seen that

$$E = \frac{dV}{dr} = -\frac{2e}{r_0} \tag{34}$$

and similarly

$$E_1 = \frac{dV}{dr} = -\frac{2e_1}{r_0}$$

since r_0, the wire radius, has been assumed to be the same in the two cases considered.

Dividing (38) by (35), we obtain the relation:

$$\frac{E_1}{E} = \frac{\dfrac{V_1}{\log_e \dfrac{\left(\frac{a^2}{r_1}\right)^2 - r_1^2}{2r_1 r_0}}}{\dfrac{V}{\log_e \dfrac{a}{r_0}}}$$

Now in any problem in heat conduction we may say, since

$$E_1 = \frac{dV_1}{dx} \text{ and } E = \frac{dV}{dx}$$

and the temperature T may be considered analogous to V, that $\frac{dT}{dx}$ is the temperature gradient from a wire. Further, dT/dx determines Q, the heat loss by conduction which may be expressed in watts per unit length of the wire. We postulate further that the wire temperature T is the same in both cases considered, i.e., the single co-axial wire and the two wires symmetrically placed as stated above. Hence in the electrical analogy $V = V_1$, so we may write

$$H = \frac{W_{c_1}}{W_c} = \frac{\log_e \dfrac{a}{r_0}}{\log_e \dfrac{\left(\frac{a^2}{r_1}\right)^2 - r_1^2}{2r_1 r_0}} \tag{39}$$

where W_c is the heat conducted *per unit length* from a wire of radius r_0 co-axial with a cylindrical container of radius a. W_{c_1} is the heat conducted *per unit* length from *one* wire when two are present as postulated.

Similarly when n wires or n equal lengths of the looped wire are present and arranged symmetrically about the axis of a cylinder of radius a and equidistant from the cylinder axis, it may be shown *that when* r_1 *is large compared to* r_0, the heat loss per unit length of *one* of the lengths of wire in terms of the heat loss per unit length of a single co-axial wire of the same diameter and operated at the same temperature T_2 is expressed by

$$W_{c(n)} = \frac{\log_e \dfrac{a}{r_0}}{\log_e \dfrac{\left(\frac{a^2}{r_1}\right)^n - (r_1)^n}{n r_1^{n-1} r_0}} \tag{40}$$

when the cylinder wall temperature T_1 is the same in both cases.

This may be simplified to

$$H = \frac{W_{c(n)}}{W_c} = \frac{\log_e \dfrac{a}{r_0}}{\log_e \dfrac{r_1}{n r_0}\left[\left(\dfrac{a}{r_1}\right)^{2n} - 1\right]} \tag{41}$$

Assume $T_2 = 1050$ deg. K. = wire temperature.

$T_1 = 293$ deg. K. = wall temperature.

$r_0 = 4.45 \times 10^{-3}$ cm. = wire radius.

$r_1 = 1$ cm. = distance between any wire axis and the axis of the cylindrical container, where $n = 4$ and the wires are equidistant from each other.

For the case of a single co-axial wire of this diameter we have seen that $W_c = 2.834$ watts per cm. length of filament in 20 cm. pressure of hydrogen.

Now if the radius of the container, a, equals 4 cm., calculation by means of equation (45) shows that 1.275 watts are lost by conduction per cm. length of any one length of the filament when the filament is looped into four equal lengths as postulated, i.e., $H = 0.45$.

Similarly with the filament in four equal lengths and $a = 2.0$ cm., 1.78 watts are lost by conduction per cm. length of *one* length of the filament, i.e., $H = 0.628$.

It is obvious from these calculations that looped wire ballasts would have totally different operating characteristics from those obtained in the single co-axial filament case.

The writer extends his thanks to Mr. W. G. Baker for much assistance in preparing the nomogram.

The Production of Fluorescence and Phosphorescence by Radiations from the Carbon Arc Lamp

By W. S. Andrews

General Engineering Laboratory, General Electric Company

In our February issue we presented an article by Mr. Andrews which discussed the production and characteristics of cold light. In it was included a tabulation of substances which are capable of emitting visible cold light. Two divisions of this tabulation, fluorescence and phosphorescence, form the basis of the present article. Mr. Andrews tells here of the very beautiful luminous effects which may readily be produced by the excitation of certain substances with specially screened radiation from an ordinary carbon arc lamp.—Editor.

The invisible ultra-violet spectrum has been conveniently divided into three regions as follows:

Near region: (Meaning near to the visible spectrum). Including wavelengths of 390 to 300 mμ.(1)

Middle region: Including wavelengths of 300 to 200 mμ.

Extreme region: Including wavelengths of 200 mμ and lower.

Certain compounds, such as zinc sulphide, are excited to fluorescence and phosphorescence by a wide range of ultra-violet radiation, while other compounds, as for example salicylic acid and most of its salts, show results only in the middle or extreme regions; and again, other substances appear to be most sensitive to radiation in the near region.

The high-tension disruptive arc between iron terminals is rich in ultra-violet rays of the middle region, and it excites very beautiful fluorescent effects in a great many substances. The apparatus required for this purpose however is not always available, and it is also somewhat dangerous if manipulated by an unskilled operator, by reason of the necessary high voltage.

Professor R. W. Wood, of the Physics Department of Johns Hopkins University, was the first to discover and demonstrate the highly interesting fluorescent effects shown by certain substances when exposed to what may be termed the "twilight-to-darkness" region, which includes a band in the dimly visible violet and runs into an adjacent band in the near region of the invisible ultra-violet.

Professor Wood produced these rays by screening the light of a quartz mercury lamp through a special dark glass, the composition of which was carefully determined by him for this work. The results obtained were interesting in the extreme, and permitted demonstrating the fluorescence of the teeth, the lens of the eye, the finger nails, and even the bare skin of each individual in a fairly large audience.(2)

Here again, however, the apparatus employed is rather expensive, and it also requires expert manipulation for its proper exhibition.

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(1) One millimicron (or mμ) $= \frac{1}{1{,}000{,}000}$ millimeter.

(2) A full account of the numerous novel and curious effects produced by this radiation is given in a paper, "Communications au Moyen de rayons lumineux," by Prof. R. W. Wood, *Journal de Physique Théorique et Appliquée*, Series 5, v. 9, pp. 77-90, March, 1919, and in the many abstracts which appeared in the *Scientific American* and other periodicals at that time.

It is, therefore, the purpose of this article to describe a substitute apparatus which is both simple and safe, and with which many fine fluorescent effects may be produced.

The source of light is an ordinary carbon arc lamp, having its large component of visible light screened out or absorbed by a suitable glass filter. The lamp is enclosed in a ventilated light-tight box having a window about six inches square cut in one side, into which is fitted a plane square filter of "red-purple ultra" glass.(3) This glass is nearly opaque to visible light, as it transmits only a band in the extreme red and another in the extreme visible violet.

The rays that pass through this filter (not including the band in the extreme red) are of that shadowy borderland, termed the "near region," which includes barely perceptible visible light together with a band of the first invisible ultra-violet. Thus the fluorescent effects which the invisible rays will produce are not masked and over-powered by any bright visible light. By increasing the thickness of the filter, the extreme red rays may be completely eliminated, but in this case a more powerful arc is desirable to compensate for the increased absorption at the violet end of the spectrum. The writer has found, however, that a carbon arc of only 5 or 6 amp. will produce very beautiful fluorescent effects on the following compounds, when its light is screened through a single thickness of the red-purple ultra glass.(3)

Some Fluorescent Substances

Vaseline shows a light blue fluorescence, especially the purest kind that is used in surgery and sold in tubes of flexible metal. Other grades of vaseline, and in fact nearly all of our native hard and soft mineral fats fluoresce more or less brightly in colors ranging from blue to white.

Vaseline can be conveniently dissolved in carbon tetrachloride (which is non-inflammable) and fabrics may be saturated with the solution. The liquid will evaporate quickly leaving a coating of vaseline on the fabric which, though invisible under ordinary light, will fluoresce under the screened rays.

A valuable use for this filtered light has been found in detecting the adulteration of vegetable and animal oils (such as linseed, castor, and lard oils) with cheap mineral oil, as a very small amount of the latter imparts a fluorescence to them which the pure vegetable and animal oils do not possess.

Dr. Alexander E. Outerbridge, Jr., was the discoverer of this simple but positive method for testing the purity of these vegetable oils.(4) In his experiments on this subject, Dr. Outerbridge used an unscreened carbon arc. Much clearer and brighter effects are produced, however, by screening the light as previously described.

Anthracene is a solid hydrocarbon $(C_6H_4)_2(CH)_2$ which accompanies naphthaline in the last stages of the distillation of coal tar. It is freely soluble in hot carbon tetrachloride, and if white blotting paper or cotton cloth is soaked in the warm solution and dried it will fluoresce a bright blue under the screened rays. Still brighter effects may be produced by grinding the anthracene, with a thin solution of gum arabic and sugar in water, to the consistency of cream, and using it as a paint. A few drops of alcohol added to the mixture will facilitate the operation of mixing and grinding.

Sublimed Anthracene shows a fine green fluorescence and may be treated as just described. The addition of a little alcoholic solution of rhodamin KY during the grinding process will impart a red color to the mixture when seen by ordinary light, but when the mixture is made in proper proportions it will appear almost pure white under the filtered rays. Different fluorescent shades of color, ranging from light green through white to a light pink, may be obtained by varying the amount of rhodamin used.

Rhodamin KY may be added to a clear solution of bleached shellac in alcohol, and applied to paper or woven stuff and dried. The fluorescence will vary in shade from orange to dark red, according to the amount of rhodamin in the solution.

Fluorescein, Eosine, and some other synthetic dyes also show various shades of orange and yellow fluorescence when treated like rhodamin.

Uranium Glass and most of the uranyl salts have a bright green fluorescence. The glass may be finely powdered so as to pass through a 200-mesh sieve and applied as a paint. Some of the less soluble uranyl salts, such as the fluoride, can also be used in this way.

Platinum-Barium Cyanide as used for fluoroscope screens in x-ray work shows a very bright green luminescence.

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(3) Made by the Corning Glass Works, and listed as G-586-A.

(4) An interesting account of the work is given in his paper "A Novel Method for Detecting Mineral Oil and Resin Oil in Other Oils," *Proceedings of the American Society for Testing Materials*, Vol. XI, 1911, pp. 650-664.

Some Fluorescent and Phosphorescent Substances

All the compounds hitherto described exhibit fluorescence, but no phosphorescence or afterglow. The following are some compounds which combine these two effects.

Zinc Sulphide in certain forms is strongly fluorescent, chiefly in shades of orange, yellow, and green. These zinc sulphide preparations also generally show a bright phosphorescence of similar color. They can be finely powdered and used as paints, as previously described.

Barium Sulphide, when properly prepared, will fluoresce with a rich orange yellow, and it will have a fairly persistent afterglow of the same color.

Strontium Sulphide displays a greenish yellow fluorescence and an afterglow of a similar color.

Calcium Sulphide is known in the trade as "Balmain's Luminous Paint." A weak red-violet fluorescence is shown by this compound but its afterglow is fairly bright blue and very persistent, though it gradually fades to a whitish color.

If the dark glass screen is withdrawn,(5) and the full intensity of the arc is thrown onto any of these sulphides, their fluorescence will be masked and overpowered, but the phosphorescence thus excited will be very much brighter than when they are acted on through the screen. Particularly is this the case with calcium sulphide, for it will sometimes glow for hours in a dark room after exposure. There is however a considerable difference in the behavior of all these sulphides, owing to the varied treatment in manufacture and the relative purity of their ingredients.

Various Solutions put up in clear glass bottles or test tubes also glow with many bright fluorescent colors under the filtered rays, such as:

	Dissolved in	
Magdala Red	alcohol	*Red Orange*
Rhodamin KY	alcohol	*Orange*
Fluorescein & Rhodamin	water	*Yellow*
Fluorescein	water	*Yellow Green*
Uranine	water	*Yellow Green*
Esculine	water	*Blue*
Esculine & Rhodamin	water	*Violet*

By varying the strength and proportions of the different mixtures, an endless variety of beautiful fluorescent shades may be produced; but in all these cases the colors exist only in the solutions for the dry chemicals are not responsive.

Natural teeth show a clear white fluorescence, but artificial teeth appear almost black. Natural teeth are composed largely of calcium phosphate which in this condition is responsive to the rays, but artificial teeth are made of porcelain which is not sensitive. For the same reason ivory and bone exhibit a white luminescence, and also, to a less extent, the finger-nails. Even the clean bare skin shows a pale fluorescence.

It appears, however, that in all of these cases the fluorescence is caused by some organic constituent, since pure calcium phosphate is unresponsive. If ivory or bone is heated to redness, so as to decompose and drive out all organic compounds, sensitivity to the rays is lost. Boiling in water, however, for an indefinite time does not produce any effect, neither does prolonged soaking in alcohol. Digestion in weak sulphuric acid, however, dims the fluorescence and weak hydrochloric acid almost destroys it.

White silk is brightly fluorescent, but most cotton or linen fabrics are only weakly so. In this way white mercerized cotton, which may have the appearance of silk, may be positively identified. Some samples of white paper also show fluorescence, while other samples do not.

In 1912, Dr. M. Alexander McDermott kindly presented to the writer a small sealed bottle containing an aqueous extract of fireflies (Photinus pyralis). This liquid is only weakly luminescent under radiations from the iron spark, but under the screened rays of the carbon arc it shows a fine blue fluorescence.

As ordinary glass is transparent to these filtered rays any substance contained in a clear glass bottle can be conveniently investigated.

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(5) Care must be taken to protect the eyes with colored glasses when operating the unscreened arc lamp.

The Increase in Thermal Efficiency Due to Resuperheating in Steam Turbines

By W. E. Blowney and G. B. Warren

Turbine Engineering Department, General Electric Company

Experience has shown that as the ratio of the number of stages of a turbine operating in the superheat region to the number operating in the moisture region is increased, the actual thermal efficiency is improved at a rate far in excess of the theoretical value. The authors of this article have made a careful study of the situation based on a large number of tests, and report that the heat input of a turbine installation may be decreased from six to seven per cent by resuperheating the steam between stages. It may even prove advantageous to resuperheat several times. In these days of the extreme importance of small increments of efficiency, the information which the authors give is of such great interest as to lead us to reprint it from the *Journal of the American Society of Mechanical Engineers*.—Editor.

Introduction

The primary purpose of the present article is to set forth the analysis of the data available to the writers relative to the increase in turbine efficiency with increased initial superheat, and to apply such analysis to a determination of the probable gain due to resuperheating in high-pressure turbine installations. In connection with this, the resulting resuperheat cycles have been combined in two instances with regenerative or steam-extraction feedwater-heating cycles and an analysis made of the combined gain in efficiency.

It has been recognized for a long time that whatever gain would result from resuperheating was, in the main part, due to the increase in the steam-turbine efficiency resulting from the greater superheat and reduced moisture content of the steam in the turbine rather than to the thermodynamic improvement of the heat cycle.

The data relative to the gain in turbine efficiency with increased initial superheat are, on the whole, not as complete as might be desired, particularly on large turbines, since it is difficult to vary the initial superheat over a satisfactory range in the average power station. In the main part, it has been necessary to base the present series of calculations upon tests on turbines of from 2500 to 10,000 kw. capacity, but very complete tests are available at low initial pressures and fairly complete tests are available at moderately high pressures at these capacities.

The data seem to point to the conclusion that the slope of a superheat-efficiency curve is almost independent of the type of turbine. This is borne out by published superheat-efficiency curves on other machines which agree very closely with the data that have been used.

The superheat-efficiency curves available to the writers have been plotted in comparison, graphically averaged to give curves of representative slope, and then these average curves have been analyzed on such a basis as to make the results available for determining the increase in the turbine efficiency due to resuperheating. This, when combined with the increase in the thermal efficiency of the heat cycle, gives the overall improvement in turbine heat consumption which can reasonably be expected.

Definitions

In this article improvements in the heat consumption of a turbine will be spoken of as percentage improvements in the thermal efficiency. For example: A 10 per cent change in a thermal efficiency which, let us say, is 30 per cent to begin with, would mean that the improved efficiency is 33 per cent. Percentage changes in the efficiency ratio of a turbine or turbine stage are taken in the same sense.

The following terms are used as defined:

Thermal efficiency of turbine: The ratio between the heat equivalent of the output of the turbine at a prescribed point and the total net heat input into the turbine.

Turbine efficiency: The ratio between the heat equivalent of the output of the turbine at a prescribed point and the adiabatic available energy between the pressure and temperature limits through which the turbine works.

Turbine output: Throughout this article, for the sake of simplicity, unless otherwise specified, the turbine output has been assumed to be the output at the turbine wheel hubs and the efficiencies have been based on this value. The losses due to the bearings, high- and low-pressure packings, generator, etc., have thus been excluded and the leaving velocity loss has been assumed to be zero, since these vary with each installation and design.

Fraction of Adiabatic Drop at Which Resuperheating Takes Place: This value is the ratio of the adiabatic drop which takes place before resuperheating as compared to the total adiabatic heat drop from the initial to the final pressures along the initial entropy line.

Assumptions Used in Analysis of the Gain in Turbine Efficiency with Increased Initial Superheat

Curve A-3, Fig. 1, shows a typical turbine-efficiency-initial-superheat curve. The improvement in the turbine efficiency as the superheat increases is due to an improvement in the individual stage efficiency and to an improvement in the reheat factor R with increasing initial superheat.

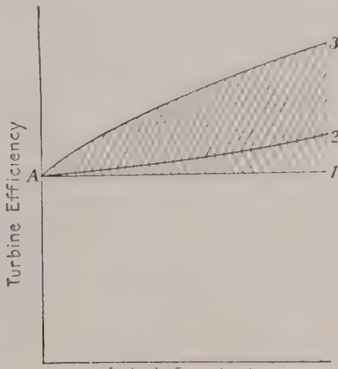

Fig. 1. Typical Superheat Turbine-efficiency Curves

A modern turbine is made up of a number of individual stages, each stage taking a part of the pressure drop, and thus a part of the heat or energy drop. It would be thought at first that the efficiency of the complete turbine would be the weighted average (weighted according to the heat drop taken per stage) of the individual stage efficiencies. Such, however, is not quite true. Since each stage is less than 100 per cent efficient, a certain amount of energy is lost in each stage and is thus reconverted into heat which is used in "reheating" the steam. This reheating of the steam in each stage thus makes a greater amount of energy available in the succeeding stages, since it increases the entropy and the total heat. Therefore, the summation of the adiabatic energy drops of each stage is always greater than the adiabatic energy drop over the entire machine. Expressed in symbols, if

i_1 = initial total heat in the steam per lb., and if

i_2 = final total heat in the steam after adiabatic expansion from i_1 to the final back pressure, then

$i_1 - i_2$ = the available energy in B.t.u. per lb. of steam, and if

Δi = the fraction of the heat drop available for a single stage, then, on account of the reheating mentioned above,

$$\Sigma \Delta i = R\ (i_1 - i_2) \tag{1}$$

where R is the so-called "reheat factor." Let

W = the work done in the turbine in ft. lb. per lb. of steam and

$A = \frac{1}{778}$ or heat equivalent of 1 ft. lb.

Then the turbine efficiency will be

$$\eta_t = AW/(i_1 - i_2) \tag{2}$$

and we might define the average individual stage efficiency as

$$\eta_s = AW/\Sigma \Delta i \tag{3}$$

But from equation (1)

$$\frac{AW}{\Sigma \Delta i} R = \frac{AW}{(i_1 - i_2)} \tag{4}$$

therefore,

$$\eta_t = R \eta_s \tag{5}$$

R is always greater than unity since the return of heat to the steam due to the losses in the machine always makes $\Sigma \Delta i$ greater than $i_1 - i_2$.

In general, for a given ratio of initial and final pressures, the greater the proportion of the machine in the superheat region, the greater the value of R. (See Fig. 4.)

If, therefore, the stage efficiency η_s remains constant as the initial superheat increases, the turbine efficiency will follow some such line as A-2 in Fig. 1. The difference between the curve A-2 and the actual curve A-3 must then be due to an increase in the average stage efficiency.

There is reason to believe from data available that there is practically no change in the individual turbine stage efficiency with increase in the average superheat of the steam in the stage. The change in the average stage efficiency with superheat must then be due to the change in the stage efficiency with change in the moisture content of the stages in the moisture region. The method of analysis, therefore, to find the average correction to apply to the stage efficiency, is to correct for the moisture content in the stage on the assumption that the expansion takes place in thermal equilibrium, and that the reduced efficiency with increased moisture content is due to the mechanical effect of the moisture in the steam. This method then involves no assumption regarding the probable degree of supersaturation of the steam during the expansion.

The writers are fully aware of the possibility, as brought out by H. M. Martin(1) and Prof. H. L. Callendar,(2) that a part of the improvement in turbine efficiency with increased superheat may be due to supersaturation, particularly since supersaturation or failure of the steam to condense and so give up its latent heat during expansion is known to exist to a certain extent in the extremely rapid expansion of steam in turbine nozzles. The exact extent of such supersaturation in turbines is, however, unknown to the writers at present; and, so far as can be seen, the results of the present analysis, when applied to the resuperheating problem, would not be different had the probable degree of supersaturation been considered.

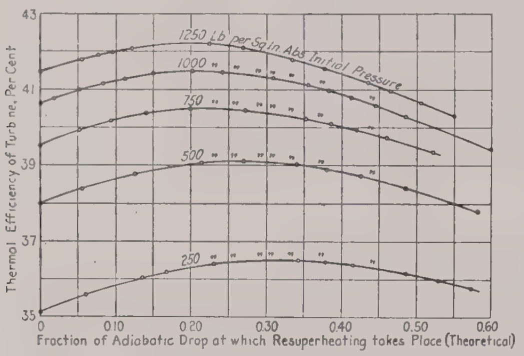

Fig. 2. Theoretical Thermal Efficiency of Heat Cycles at Different Initial Pressures and at Different Points of Resuperheating. (Turbine Efficiency 100 Per Cent)

(Initial and resuperheating temperature 750 deg. F. Back pressure 1 in. Hg abs.)

Data Available and Its Analysis

Approximately twenty complete superheat efficiency curves were available. These had been obtained on ten different turbine combinations. The machines were all of the multi-stage impulse type, the initial pressures ranged from 60 to 200 lb. per sq. in. absolute, and the back pressures were all 1½ in. Hg. absolute. These curves have been obtained at constant speed, but at many different points on the speed curves of the different machines. The tests were in many cases made practically under laboratory conditions.

In using these data in connection with a determination of the gain due to resuperheating, it was necessary to consider that in case a turbine was designed for a resuperheating installation, a greater amount of bucket speed would be put into the machine to take care of the increased available energy and to keep the ratio of the bucket speed to jet speed constant. Therefore, the superheat-efficiency curves had to be corrected to such a basis that the ratio of bucket speed to steam-jet speed was a constant. That is, it was assumed that the turbine was speeded up in proportion to the square root of the increased available energy as the superheat increased. This necessitated speed curves at constant superheat on the different machines, in order to make such corrections. These speed curves were available in most cases.

When these speed corrections had been made, the slopes of the curves with 60 lb. per sq. in. initial pressure and those with 200 lb. per sq. in. initial pressure were averaged separately. Then by a cut and try process, an average stage efficiency and a correction for moisture were obtained which, if applied together with the correct reheat factor, which had been previously calculated, enabled calculated superheat efficiency curves to be obtained. These calculated curves coincided with the average test curves to within a fraction of 1 per cent throughout the entire range of superheat from 0 to 300 deg. F. superheat at both initial pressures. The correction for moisture came out in each case to be 1.15 per cent decrease in the turbine stage efficiency for each 1 per cent increase in the average moisture content in the stage. As an example, if the stage efficiency when operating with superheated steam were 85 per cent, with 10 per cent moisture in the steam it would be

$$0.85(100-1.15\times 10) = 75.2 \text{ per cent}$$

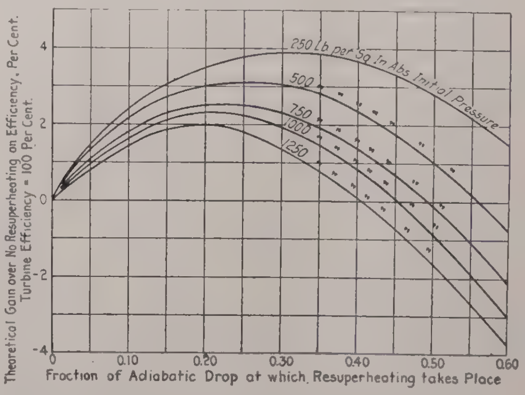

Fig. 3. Theoretical Gain in Efficiency of Heat Cycles Due to Resuperheating at Different Points and for Different Initial Pressures

(Initial and resuperheating temperature 750 deg. F. Back pressure 1 in. Hg abs.)

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(1) "A New Theory of the Steam Turbine," *Engineering*, Vol. 106, p. 1.

(2) "Properties of Steam."

This value of 1.15 per cent decrease in stage efficiency with each 1 per cent increase in the moisture content has been used in the following analysis of the gain due to resuperheating.

The value of 1.15 per cent change in stage efficiency agrees very closely with the 1 per cent change per 1 per cent change in moisture content given by K. Baumann,(3) and differs in the right direction, since the value obtained here is on the basis of a change in turbine speed to correspond with a change in the superheat.

Application To Resuperheating

Before applying the preceding analysis to the calculation of the gain in turbine efficiency due to resuperheating, it was necessary to calculate the theoretical thermal efficiencies of the resuperheating cycles which were to be studied and to determine the percentage gain in each case over the corresponding cycle without resuperheating. The resulting curves are given in Figs. 2 and 3. It will be noted that the theoretical savings shown in Fig. 3 are comparatively small, the maximum being 3.9 per cent on the 250-lb. curve, and the gain decreasing as the initial pressure increases.

After determining the correction of 1.15 per cent change in efficiency per 1 per cent in moisture content discussed in the preceding paragraphs, it was necessary to make certain assumptions regarding the variations in the dry-stage efficiency, and to determine the proper reheat factors to be used with the various steam conditions used in the calculations. By dry-stage efficiency is meant the efficiency of a turbine stage where the steam is dry or superheated.

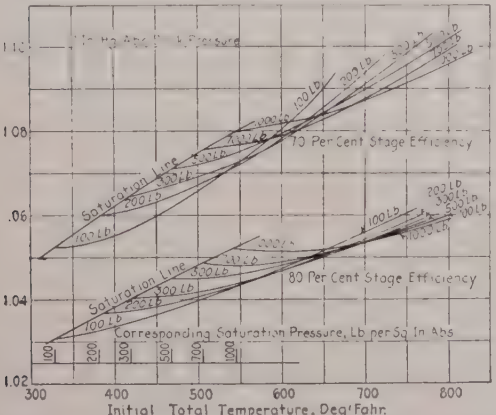

Fig. 4. Reheat Factors for an Infinite Number of Stages at Various Initial Pressures, Initial Temperatures and Stage Efficiencies

(Back pressure 1 in. Hg abs.)

In general, the higher the pressure in a stage, the lower will be its efficiency due to the necessarily smaller nozzles and buckets and to the higher rotation and packing losses. Inasmuch as the stage efficiency is largely a matter of design, two assumptions were made regarding its variation with pressure: (1) That the dry-stage efficiency decreased in a certain manner as the pressure increased, and (2) that the dry-stage efficiency was constant throughout the turbine. As will be noted in later paragraphs, the results obtained using these two assumptions differ slightly.

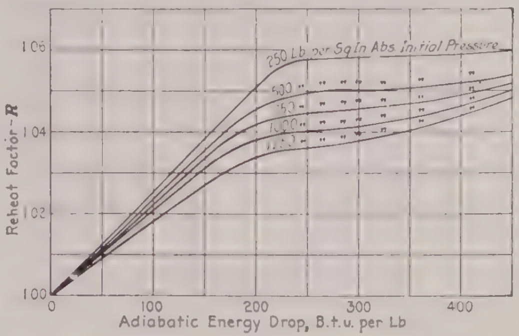

Fig. 5. Reheat Factors for an Infinite Number of Stages at Various Initial Pressures as Function of the Adiabatic Energy Drop

(80 per cent stage efficiency, 750 deg. F. initial temperature.)

Due to the fact that the curves given in this paper do not include last-stage leaving losses, bearing losses, high- or low-pressure packing losses, or generator losses, all thermal efficiency curves should be considered as being relative and not absolute in value.

The reheat factors which were used are given in Figs. 4 and 5. In both of these sets of curves the reheat factors are for a turbine having an infinite number of stages. A turbine having from fifteen to twenty stages will have a reheat factor in which the part greater than unity will have a value approximately 0.9 of the value with an infinite number of stages. This factor of 0.9 was used in all calculations.

It will be noted also that the reheat factor curves given in Fig. 5 are all on the basis of an 80 per cent stage efficiency.

In order to obtain the reheat factor for efficiencies other than 80 per cent, the following approximation was used:

If $x = R' - 1$, where R' is the reheat factor for an infinite number of stages at 80 per cent stage efficiency, it was assumed that the part x was proportional to the difference between 100 per cent and the per cent stage efficiency, which is very nearly true. These assumptions then make the reheat factor used

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(3) "Some Recent Developments in Large Steam Turbine Practice," *Jour. Inst. E. E.*, Vol. 59, 565.

$$R=1+0.9\,(R'-1.0)\left(\frac{100-\eta_s}{20}\right)$$

where R is the reheat factor used and η_s is the average stage efficiency in per cent.

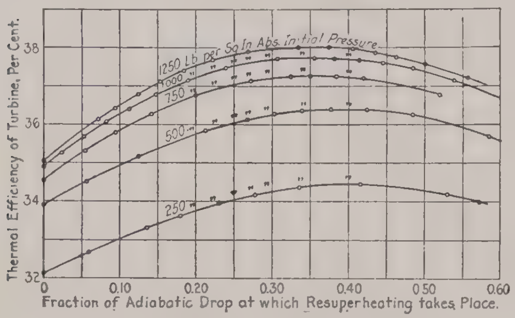

Fig. 6. Thermal Efficiency of Turbine for Various Initial Pressures as Function of Point of Resuperheating

(Initial and resuperheating temperatures 750 deg. F. Back pressure 1 in. Hg abs. *Variable stage efficiency as a function of stage pressure.* No pressure drop in resuperheater.)

Results

Figs. 6 and 7 show the thermal efficiencies obtained for different points of resuperheating for the variable and constant dry-stage efficiency assumptions and with 250, 500 750, 1000 and 1250 lb. per sq. in. absolute initial pressure and an initial and resuperheat temperature of 750 deg. F. These curves include the improvement in the turbine efficiency due to resuperheating and were obtained as follows:

Where the portion of the turbine under consideration was entirely in the superheat region, the end point D (see Fig. 8) was determined by multiplying the average stage efficiency by the reheat factor and subtracting the product of the result times the heat drop AC from the initial total heat A. Where a portion of the part of the turbine under consideration was in the moisture region, such as shown by the line EH, a "cut and try" process had to be used. An assumption was made regarding the location of point H and the per cent moisture at this condition was noted. It was assumed that the average moisture content per stage of the part of the machine in the wet region was one-half the final moisture content at H. Using the 1.15 per cent moisture correction previously described and the assumed dry-stage efficiencies under consideration, the efficiency of that portion of the machine in the moisture region was calculated. On the assumption that the state curve from E to H was a straight line and weighing the efficiencies in the wet and dry portion of the machine according to the energy drops b and m in the wet and dry portions of the turbine respectively, the average stage efficiency from E to H was determined. The turbine efficiency was obtained by multiplying this by the proper reheat factor obtained from Fig. 4 and the formula previously given for R. Knowing this value, the closeness of the first approximation to the location of H was checked. Two or three approximations were usually all that were necessary to locate H. It was recognized that the assumption of a straight-line state curve between E and H was slightly in error, but it was not serious enough to affect the final results to any appreciable extent.

Increase in Thermal Efficiency of the Turbine with Resuperheating

Figs. 9 and 10 were obtained from Figs. 6 and 7 respectively by subtracting the thermal efficiency without resuperheating from the thermal efficiency with resuperheating at a given point and at a corresponding initial pressure, and dividing the difference by the thermal efficiency without resuperheating. These curves show the order of magnitude of the percentage gain in thermal efficiency due to resuperheating. No account has been taken of the pressure drop in the resuperheater and connected piping, as this will, of course, depend upon the particular design. Such drop will probably reduce the gain by ½ to ¾ of one per cent.

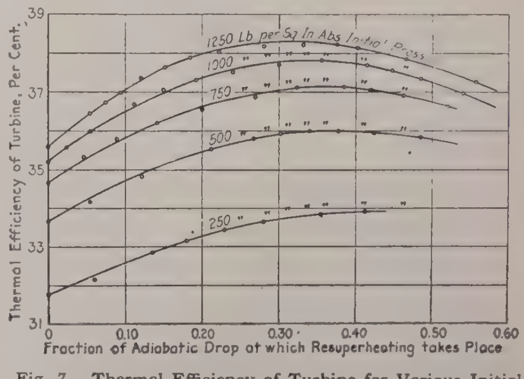

Fig. 7. Thermal Efficiency of Turbine for Various Initial Pressures as Function of Point of Resuperheating

(Initial and resuperheating temperatures 750 deg. F. Back pressure 1 in. Hg abs. *Constant stage efficiencies.* No drop in pressure in resuperheater.)

It is interesting to note that the gain, considering the change in turbine efficiency, is greater at the higher initial pressures, whereas the theoretical gain shown on Fig. 3, considering the heat cycle alone, is lower at the higher pressures. This is due to the fact that a greater portion of the turbine is operating in the moisture region with the high initial pressures and so is susceptible of greater improvement.

It should also be noted by reference to Fig. 15 and in conjunction with Figs. 6, 7, 9 and 10 that the best point for resuperheating comes at approximately one-fifth to one-sixth of the initial pressure. This gives resuperheating pressures for initial pressures of 500 lb. per sq. in. and more, which do not require resuperheating piping of excessive size.

The greater gain shown by the assumption that the dry-stage efficiency decreased with increasing pressures in the stage is due to the fact that the gain in turbine efficiency from superheating is greatest in the low-pressure end where the efficiency is the highest under the variable efficiency assumption. This results in a greater improvement than on the assumption of a constant stage efficiency. The variable stage efficiency is the more probable condition, considering the design of present-day machines.

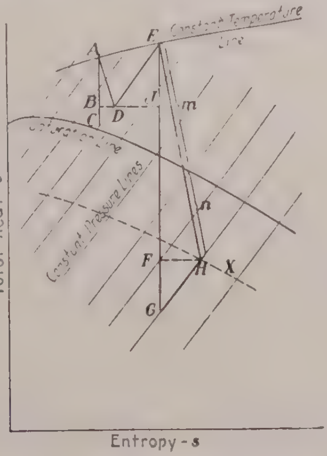

Fig. 8. Typical Expansion Lines on Mollier Diagram

In order to determine the effect of different initial and resuperheat temperatures upon the gain in thermal efficiency, a set of calculations was made on the assumption that the initial and resuperheat temperatures were varied from 750 deg. F. (corresponding to the other calculations) to 550 deg. F. total temperature. The initial and resuperheat temperatures were assumed equal in all calculations, and the point of resuperheating was taken at a ratio of 0.355 of the adiabatic drop for the 750 deg. F. condition with 1000 lb. per sq. in. absolute initial pressure. This put the resuperheating pressure at 150 lb. per sq. in. absolute. The results of this calculation are shown on Fig. 11, and show that the percentage gain in thermal efficiency is approximately constant at this resuperheating pressure irrespective of the maximum temperature of the cycle so long as the resuperheating temperature equals the initial temperature. This is in marked contrast to the theoretical gain with increased initial and reheat temperature, as also shown in Fig. 11.

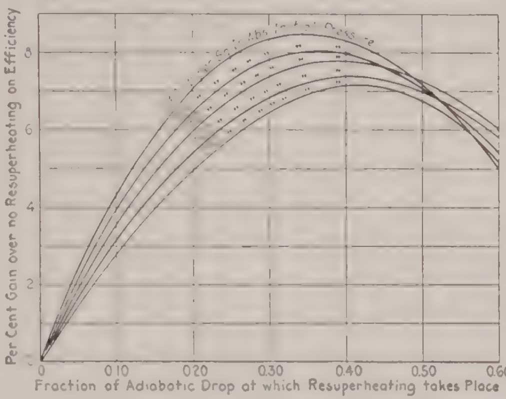

Fig. 9. Per Cent Gain in Thermal Efficiency of Turbine Due to Resuperheating as a Function of Fraction of Adiabatic Drop After Which Resuperheating Takes Place

(Initial and resuperheating temperatures 750 deg. F. Back pressure 1 in. Hg abs. *Variable stage efficiency as function of stage pressure.* No drop in pressure in resuperheater.)

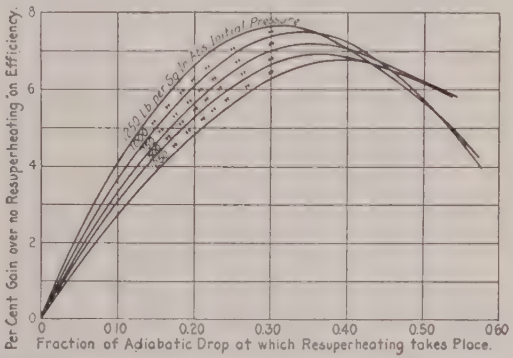

Fig. 10. Per Cent Gain in Thermal Efficiency of Turbine Due to Resuperheating as a Function of Fraction of Adiabatic Drop After Which Resuperheating Takes Place

(Initial and resuperheating temperatures 750 deg. F. Back pressure 1 in. Hg abs. *Constant stage efficiency.* No pressure drop in resuperheater.)

Fig. 12 shows comparative curves giving the per cent gain in thermal efficiency when reheating or resuperheating at various fractions of the adiabatic drop, with initial temperatures and resuperheat temperatures of 750 deg. F. in one case, and in the other case equal to the temperature of saturated steam at the 1000 lb. per sq. in. absolute initial pressure. These curves show that the fraction of the adiabatic drop at which it is best to resuperheat is slightly changed by the initial and resuperheating temperature, and that the maximum possible gain is somewhat greater in the case of the lower initial and resuperheating temperature. These curves indicate that the best point for resuperheating is not necessarily the point at which the steam in the high-pressure turbine loses its superheat, as is quite commonly believed.

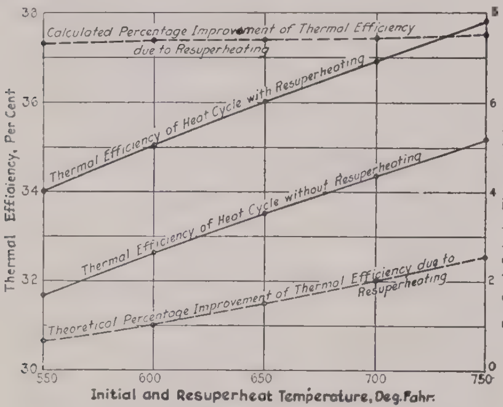

Fig. 11. Thermal Efficiency of Turbine and Per Cent Gain Due to Resuperheating as Function of Initial and Resuperheating Temperature

(Initial and resuperheat temperatures equal. 1000 lb. per sq. in. abs. initial pressure. Reheating at 150 lb. per sq. in. abs. Back pressure 1 in. Hg abs. No drop in pressure in resuperheater. Broken line at top of figure gives calculated percentage improvement of thermal efficiency of turbine due to resuperheating.)

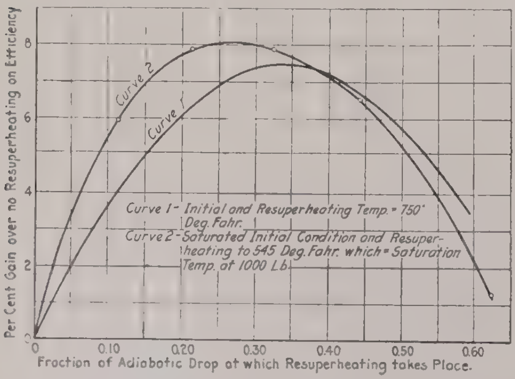

Fig. 12. Comparative Gain in Thermal Efficiency of Turbine Due to Resuperheating with Two Different Initial Temperatures at 1000 Lb. Per Sq. In. Abs. Initial Pressure and 1 In. Hg Abs. Back Pressure

(No drop in pressure in resuperheater.)

Increase in Thermal Efficiency of Turbine as a Result of Multiple Resuperheating

If it is advantageous to resuperheat once, it immediately becomes apparent that it might be more advantageous to resuperheat more than once. The complication of such an installation would of course be very considerable, but the first thing is to find out the probable gain which might result in order to determine whether such multiple resuperheating would pay, economically, considering the increased complication and investment involved.

The calculations necessary to a determination of the gain with multiple resuperheating taking into account the increase in turbine efficiency resulting from the reduced moisture content in the turbine, become quite laborious, if made following the same system as that used in the single resuperheating calculations. A system was worked out, however, whereby it was possible to obtain the gain due to multiple resuperheating from the results of the calculations for a single stage of resuperheating. The results of this calculation are shown in Fig. 13. If it is assumed that the drop in steam pressure in the resuperheaters and connected piping can be made so low as to reduce the available heat only one-half of one per cent for each resuperheating (this is somewhat lower than present practice), the net gains resulting from one or more resuperheatings will be as shown in Fig. 14. It can then be seen that the gain in going from two to three stages of resuperheating becomes so slight as to offer slight inducement to accept the increased complication and expense involved. The increase in efficiency resulting from two resuperheatings as compared to one might, however, warrant such an installation in the case of very large high-pressure base-load units.

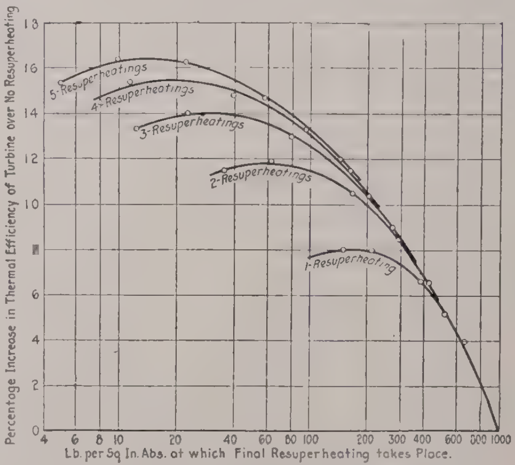

Fig. 13. Comparative Gain in Thermal Efficiency Due to Using One or More Stages of Resuperheating

(No drop in pressure in resuperheater. 1000 lb. per sq. in. abs. initial pressure. Each resuperheating to 750 deg. F Final back pressure 1 in. Hg abs.)

Fig. 15 shows the relation between the initial pressure, fraction of the adiabatic drop at which resuperheating takes place, and the resuperheating pressure, and will be of value in interpreting the results given in the preceding pages.

Effect of Resuperheating Upon Exhaust Conditions and Turbine Capacities

Fig. 16 shows several factors in the exhaust conditions of a turbine plotted as a function of the fraction of the adiabatic drop before resuperheating. The particular curves of interest are those showing the variation of the total heat rejected to the condenser and the variation in the leaving loss of the turbine as the point of resuperheating is changed. The curves have been calculated for both the 1000 lb. per sq. in. and the 500 lb. per sq. in. initial conditions.

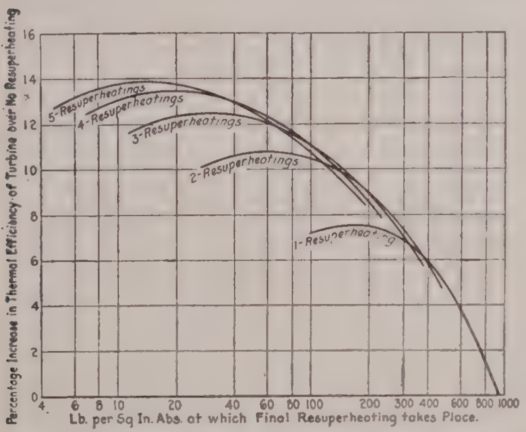

Fig. 14. Probable Actual Comparative Gain in Thermal Efficiency Due to Using One or More Stages of Resuperheating

(One-half of one per cent reduction in economy assumed for each resuperheating due to pressure drop in resuperheater and connected piping. 1000 lb. per sq. in. abs. initial pressure. Each resuperheating to 750 deg. F. Final back pressure 1 in. Hg abs.)

Curves 2 and 6 in Fig. 16 show that, per kw. of output, the heat rejected to the condenser when resuperheating at 0.35 of the adiabatic drop is approximately 89 per cent of what it would be without resuperheating. This means that the condenser can be 11 per cent smaller for any given capacity.

Curves 4 and 5 in Fig. 16 show the reduction in leaving loss of a turbine of any given capacity with any given last-stage wheel as the point of resuperheating is changed. These curves show that the exhaust loss with resuperheating becomes 65 to 67 per cent of what it would be at the same capacity and for the same last-stage wheel but without resuperheating. This is due to the reduced steam volume in the last stage per unit of output, as shown on Curve 3 in Fig. 16, and to the higher heat drop per pound of working fluid.

The reduction in leaving loss has not been credited to the machine in the analysis of the gain due to resuperheating, since in most cases advantage is taken of this fact to increase the capacity of the turbine. Since for any given capacity the percentage leaving loss is only 0.65 of what it would be without resuperheating, the capacity of the turbine could accordingly be increased to $\frac{1}{\sqrt{0.65}}$ or 1.24 times what it would be with no resuperheating and with the same percentage leaving loss.

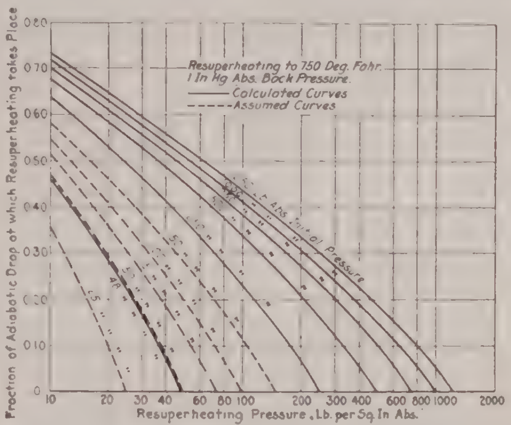

Fig. 15. Relation Between Pressure of Resuperheating and Fraction of Adiabatic Drop at Which Resuperheating Takes Place

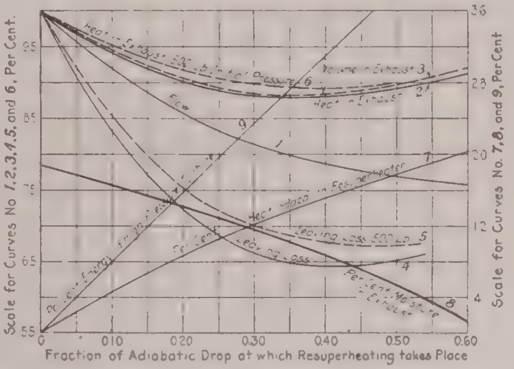

Fig. 16. Various Factors as Function of Point at Which Resuperheating Takes Place

(Unless otherwise noted on curve, initial pressure 1000 lb. per sq. in. abs.)

Gain Due to Combined Reheating and Steam Extraction Regenerative Cycles

There appears to be no practical difficulty in the way of extracting superheated steam from a turbine for use in a closed or open heater for feedwater heating purposes. It has been thought of value, therefore, to investigate whether both the resuperheating and regenerative cycles could be used together, so as to obtain the sum of the two gains of the cycles when used separately. It has been found that under the conditions which would probably obtain, the total gain in thermal efficiency of the combination is equal to practically 95 per cent of the sum of the gains in efficiency when used separately. This is on account of the very small proportion of the heat in the extracted steam which is due to the superheat.

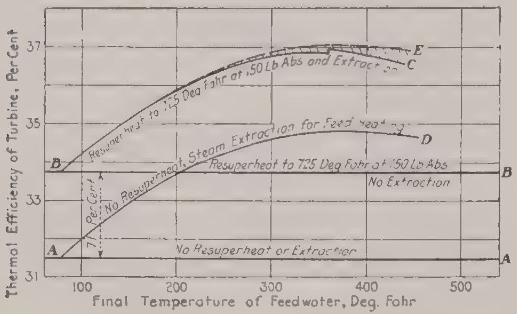

Fig. 17. Curves Showing Comparative Thermal Efficiencies of Turbines Without Resuperheating and with Steam Extraction for Feed Heating in Three Steps and of Turbines with Both Resuperheating and Extraction

(Initial pressure 515 lb. per sq. in. abs. Resuperheating at 150 lb. per sq. in. abs. Initial and resuperheating temperatures 750 deg. F. Back pressure 1 in. Hg abs.)

Figs. 17 and 18 show such combinations. The curves in these two figures have been calculated under somewhat different turbine efficiency assumptions and steam conditions, and so are not mutually comparable. The curves in each figure are, however, strictly comparable.

Fig. 17 shows a resuperheating and a non-resuperheating cycle with steam extracted at three equally spaced points for heating the feedwater in both cases. The curves were made so as to show the gain in each case when heating the feedwater to different temperatures. The feedwater heating calculations were made on an ideal basis assuming no temperature drop, no pressure drop and contraflow conditions in the heaters so that the drip from each heater left the heater at the temperature of the incoming feedwater. The drip was drained into the next lower heater in each case.

Curve *A-D* shows the thermal efficiency without resuperheating but with steam extraction for feedwater heating. Curve *B-C* shows the thermal efficiency with both resuperheating and steam extraction. Curve *B-E* is Curve *A-D* translated up a distance *A-B*, thus showing that the two gains are practically additive. The cross-hatched area is the amount by which the total increase in efficiency, when using the combinations, fails to come up to the sum of the gains when used separately. The break in the Curve *B-C* occurs at the point where the upper heater reaches the resuperheating point. Curve *B-E* breaks away from Curve *B-C* at approximately the point where the extracted steam becomes superheated.

Fig. 18 shows a similar set of calculations on the basis of resuperheating at various points in both a non-regenerative and a regenerative cycle, *A-D* being the non-regenerative cycle with resuperheating and *B-C* being the combined regenerating and resuperheating cycle. *B-E* is Curve *A-D* moved up a distance *A-B*. It can be seen that the gains are nearly additive. The breaks in the Curve *B-C* in Fig. 18 occur at the points where the resuperheating point coincides with the extraction points. These breaks show that wherever possible, it is more economical to extract at a pressure just above or at the resuperheating pressure and before the steam has been resuperheated, rather than at a point just below the resuperheating point.

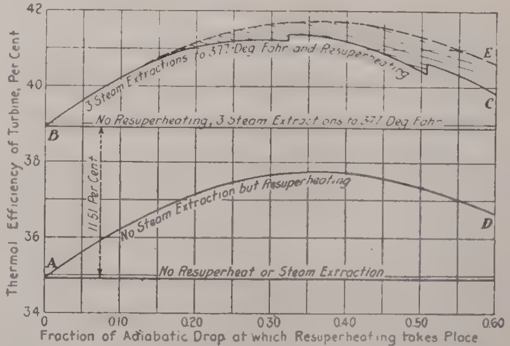

Fig. 18. Curves Showing Comparative Thermal Efficiencies of Turbines with Resuperheating and no Steam Extraction and Turbines with Both Resuperheating and Steam Extraction in Three Steps for Heating Feedwater to 337 Deg. F.

(Initial pressure 1000 lb. per sq. in. abs. Initial and resuperheating temperatures 750 deg. F. Back pressure 1 in. Hg abs.)

The writers wish to express their appreciation of the help and advice of Mr. E. L. Robinson, Dr. A. Devaud and Mr. E. G. Swanson in the preparation of this article. Fig. 4, which had been prepared by means of a method worked out by Mr. Robinson, was particularly helpful.

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Putting Alternating-Current Generators Into Service. N. L. Rea.
Power, June 23, 1925; v. 61, pp. 980-983.
(Practical suggestions for the operating man.)

Bearings

Anti-Friction Bearing Applications for Heavy Duty. J. B. Dahlerus.
I.M.E. Proc., No. 2, 1925; pp. 235-331.
(An extensive report of performance and tests.)

Coal Storage

Submerged Storage and Coal Handling Equipment at Philo.
Power, June 23, 1925; v. 61, pp. 976-979.
(Illustrated account of equipment at the Philo, Ohio, plant of the Ohio Power Co.)

Codes, Electrical

Proposed Changes in N. E. C. Insulator Requirements.
Elec. Wld., June 27, 1925; v. 85, pp. 1388-1389.

Commutators

Commutator Maintenance. N. L. Rea.
Power, June 30, 1925; v. 61, pp. 1020-1022.

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Evolution of Alternating-Current Secondary Networks. H. Richter.
Elec. Jour., July, 1925; v. 22, pp. 320-336.

Recent Developments in Automatic Network Units. G. G. Grissinger.
Elec. Jour., July, 1925; v. 22, pp. 336-338.

Electric Drive—Mining

Old Ben Coal Corporation Effects Large Savings with Modern Electric Equipment. A. W. Spaht and G. E. Marble.
Coal Age, July 2, 1925; v. 28, pp. 3-6.
(Includes operating and cost statistics.)

Electric Drive—Steel Mills

Automatic Blast Furnace. Frank W. Cramer.
Iron & St. Engr., June, 1925; v. 2, pp. 229-242.
(Includes material on electric drive of blast furnace operating machinery.)

Electric Drive—Woodworking Plants

Some Practical Details of the Power Service Layout for a Woodworking Plant. Francis A. Westbrook.
Ind. Engr., July, 1925; v. 83, pp. 316-319.

Electric Heating, Industrial

Benefits of Industrial Electric Heating. N. R. Stansel.
Elec. Wld., June 27, 1925; v. 85, pp. 1389-1390.

Possibilities of Industrial Heating. C. L. Ipsen.
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Motor Performance on Combined Secondary Networks. A. P. Fugill.
Elec. Jour., July, 1925; v. 22, pp. 316-319.

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Review of the Development of the Electric Light and Power Industry 1920-1930. David Cowan.
Elec. Wld., June 27, 1925; v. 85, pp. 1391-1401.
(This paper won the first prize in the Bonbright essay contest for the best review and forecast of the electric light and power industry for the period 1920-1930.)

Electric Transmission Lines, Artificial

Some Artificial Lines and Networks Associated with the Uniform Telephone Transmission Line.
I.E.E. Jour., June, 1925; v. 63, pp. 593-596.

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Wave-Form Analysis on Rectified Circuits. L. B. W. Jolley.
I.E.E. Jour., June, 1925; v. 63, pp. 588-592.

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Parallel Operation of D-C. Generators—Compound-Wound Type. C. Lynn.
Power, June 16, 1925; v. 61, pp. 945-947.
(Short, illustrated article.)

Electrical Machinery—Temperature

Closed Ventilation Systems for Cooling of Generators.
Power, July 7, 1925; v. 62, p. 7.
(Abstract from the 1925 report of the Electrical Apparatus Committee, N.E.L.A.)

Transformer Cooling System. R. M. Peabody.
Elec. Wld., July 11, 1925; v. 86, pp. 70-71.
(Method used by the Southern California Edison Co.)

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Notes on Modern Induction Furnace Brass Melting Practice.
Brass Wld., June, 1925; v. 21, pp. 205-207.

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Utilization of Wood Waste as Fuel in Steam Power Plants.
Mech. Engng., July, 1925; v. 47, pp. 545-554.
(A symposium.)

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Current-Transformer Methods of Producing Small, Known Voltages and Currents at Radio Frequencies for Calibrating Purposes. D. W. Dye.
I.E.E. Jour., June, 1925; v. 63, pp. 597-608.

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Hetch Hetchy Hydroelectric Development of the City of San Francisco. P. J. Ost.
Jour. Elec., July 1, 1925; v. 55, pp. 25-30.
(Illustrated description of the Moccasin plant.)

Hydro-Electric Development at the Muscle Shoals, Alabama.
Engr., July 3, 1925; v. 140, pp. 9-10.
(Serial.)

Laboratories

High-Voltage Test Room Designed for Safety.
Elec. Wld., June 27, 1925; v. 85, p. 1406.
(Short description of precautions taken by the Western Electric Co. in constructing a test room at their Hawthorne laboratory.)

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How Defects in Steel Castings Are Identified by X-Ray Examination. I. E. Moultrop and E. W. Norris.
Power, June 30, 1925; v. 61, pp. 1023-1026.
(Abstract of a paper presented before the A.S.M.E.)

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Electric Rapid Transit Inaugurated on Staten Island.
Elec. Rwy. Jour., July 4, 1925; v. 66, pp. 3-6.
(Illustrated description of equipment on the Staten Island Rapid Transit Railway.)

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Automatic Network Relay. John S. Parsons.
Elec. Jour., July, 1925; v. 22, pp. 339-344.

Repair Shops, Electrical

Taking and Recording Rewinding Data. A. C. Roe.
Ind. Engr., July, 1925; v. 83, pp. 333-337.

Strains and Stresses

Photoelasticity and Its Relation to Gear Wheels. A. L. Kimball, Jr.
Am. Mach., July 2, 1925; v. 63, pp. 7-10.
(Serial.)

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Recommendations of Electric Power Club on Installation and Care of Power Switchboards.
Ind. Engr., July, 1925; v. 83, pp. 327-332, 350.

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Elec. Jour., July, 1925; v. 22, pp. 348-351.

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Elec. Jour., July, 1925; v. 22, pp. 344-345.

Regulators on Network Feeders. C. C. Hudspeth.
Elec. Jour., July, 1925; v. 22, pp. 346-347.

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Hydraulic Turbine of New Design Developed in England. F. Johnstone-Taylor.
Engng. News-Rec., July 9, 1925; v. 95, pp. 72-73.
(Short description of the Banki turbine.)

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Automotive Electricity. Earl L. Consoliver. 665 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Internal Combustion Engines. Ed. 2. Wallace L. Lind. 266 pp., 1925, Annapolis, U. S. Naval Institute.

Mechanical Design of Overhead Electrical Transmission Lines. Edgar T. Painton. 274 pp., 1925, N. Y., D. Van Nostrand Co.

(While complete in itself, this volume forms a suitable companion to the recently-published "Electrical Design of Overhead Power Transmission Lines" by Taylor and Neale. Mr. Painton has endeavored to describe "the latest constructional details and the present trend of thought on design methods, pointing out those features which experience has shown desirable, and indicating how far the limitations of commercial manufacture enable the requirements to be fulfilled." Although intended chiefly for the designer and the engineer, the practical side of the construction of lines has not been overlooked. Charts, slide rule methods, and other labor-saving cuts have been included, and the use of the various equations presented is demonstrated by practical examples. Briefly enumerated, the subjects covered are: the nature and properties of conductors, sag and stress calculations, insulators, wood and steel poles and towers, constructional details and erection of lines.)

Metallurgy of Aluminum and Aluminum Alloys. Robert J. Anderson. 913 pp., 1925, N. Y., Henry Carey Baird & Co.

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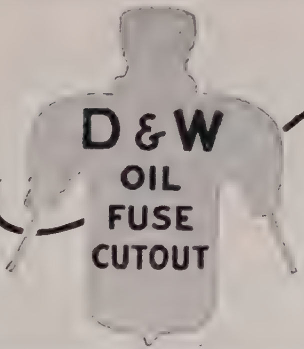
Telephone Communication. Charles A. Wright and Albert F. Puchstein. 515 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Testing of High-Speed Internal-Combustion Engines. Arthur W. Judge. 392 pp., 1925, N. Y., D. Van Nostrand Co.

Thomas Alva Edison. Francis A. Jones. 399 pp., 1924, N. Y., Thomas Y. Crowell Co.

Not quite a breaker —



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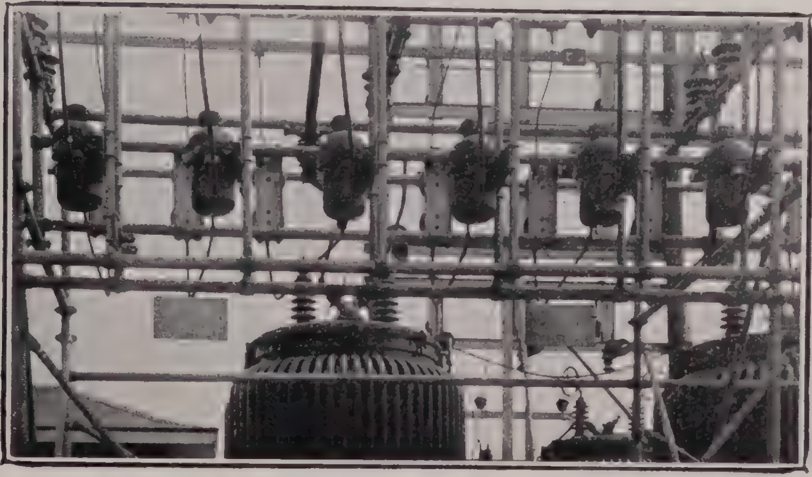

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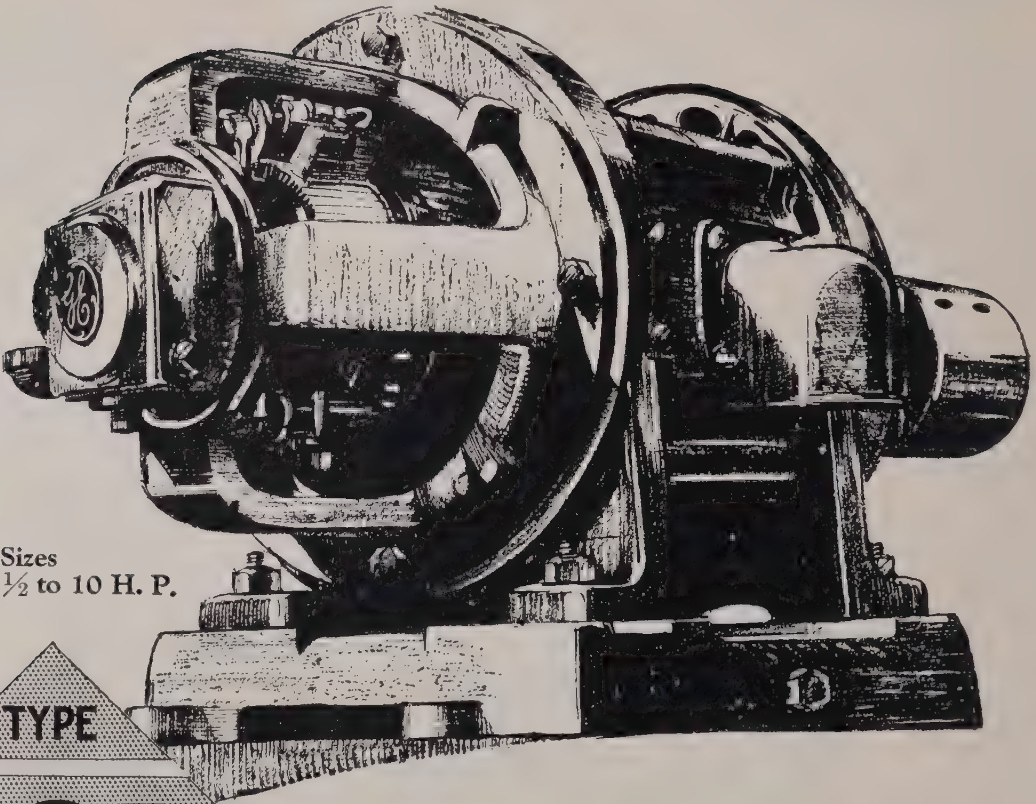

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  - —"Pull Out"
- High Efficiency
- High Power Factor
- Low Starting Current
- Low Heating
- Excellent Commutation
  - —Overload Capacity
  - —Speed Regulation
- Quiet
  - —Starting
  - —Running
- Positive operation on low voltage

Low Operating Cost—
high power

If your Single-Phase applications require reliability in the driving motor—

If you demand "lastingness" and bull-dog tenacity on your power job—

If you want the latest and best single-phase motor—

Specify the type **SCR**!

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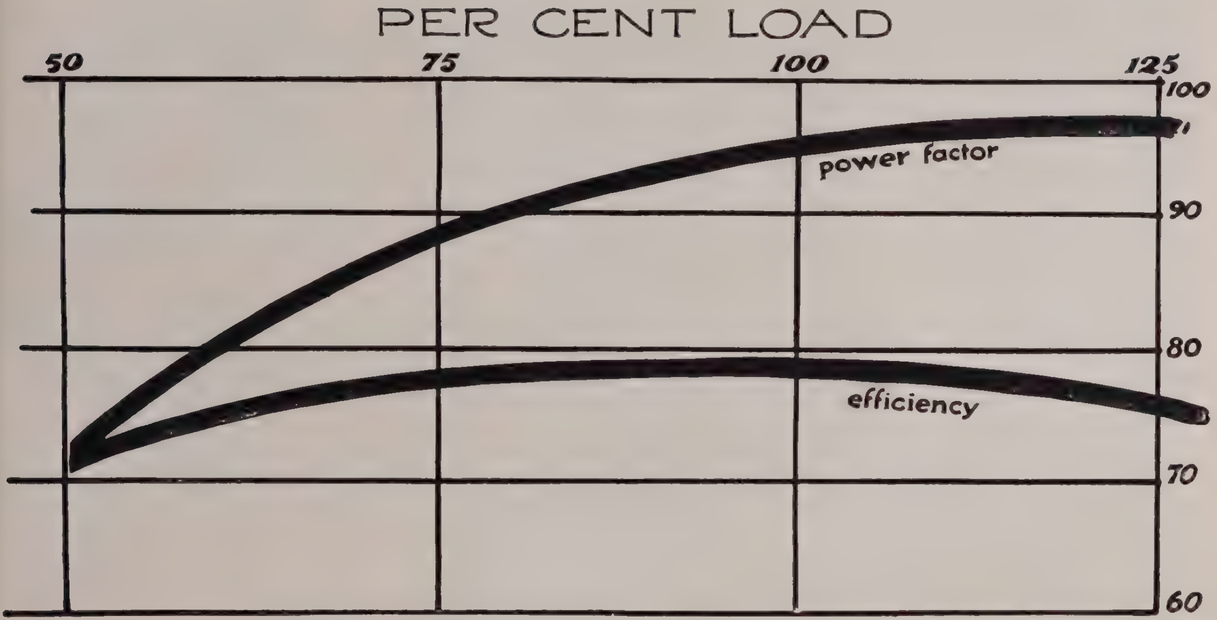

the result of
factor and efficiency

The power factor of **SCR** motors is unusually high (approaching 100%) throughout the working range!

The efficiency of the **SCR** motors as a line—as well as the efficiency of each size throughout the working range is high!

Wherever G-E Motors are installed, marked efficiency and economy are gained *and maintained* in the performance of machines they drive. Their balanced mechanical and electrical construction makes them exceptionally trouble-free and unfailing. G-E Motorized Power pays you as surely as good investment bonds. Ask your nearest G-E office for information as to your requirements.

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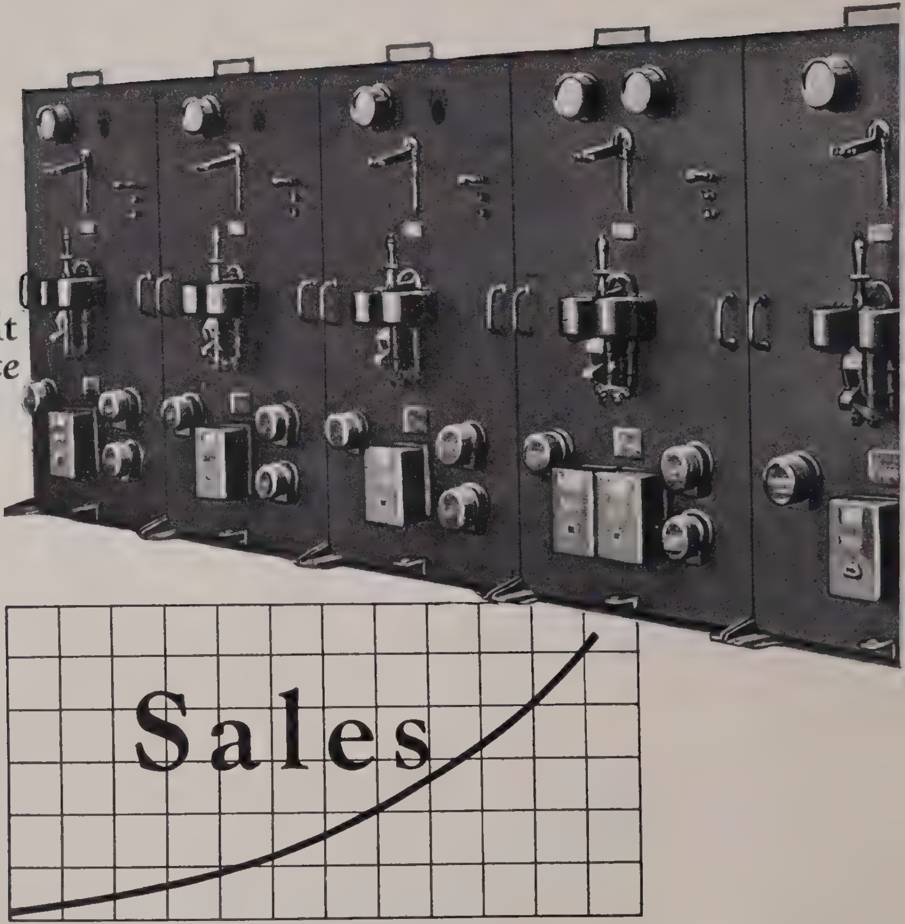

Every year a record year

General Electric builds also the other lines of Switching, Control, and Protective Equipment, which are necessary factors in the distribution of electric power. Every device involved is designed by specialists, whose work includes a study of the assembled apparatus. Users recognize the improved operation of perfected devices when properly co-ordinated in equipment that is best suited for the particular applications.

GENERAL
GENERAL ELECTRIC COMPANY, SCHENECTADY, NEW YORK

EACH year more G-E Truck type Switchboards are installed than the year before. Engineers everywhere are thinking of switchboard economy and safety and *service* in terms of G-E "Trucks".

Ten years ago General Electric built its first equipment of this type—which is still in operation. Today there are thousands of G-E Truck type Panels installed in central stations and the power plants of practically every industrial field.

Users of power at 15,000 volts, or less, should investigate the Truck type Switchboard, which is completely fabricated at the factory and has these important advantages:

Continuity of power

Only with truck panels, which are removable and interchangeable, can a "spare" panel be immediately pushed into the place of one rendered inoperative. This means practically continuous service.

Low Cost

For equal functions, equal safety, and equal convenience of operation the over-all cost of truck panels installed is less than that of other types of switchboards.

Economy

Installation, inspection, repair, and extension operations are so simplified and rendered so safe that the time for doing this work is reduced to the minimum. Losses from delays caused by a disabled switchboard are practically eliminated.

Safety to operators

All high-voltage parts are entirely inaccessible when the truck is in its housing. When the truck panel is removed from its contacts for inspection or repair, all parts on the removable unit are electrically dead.

228-6A

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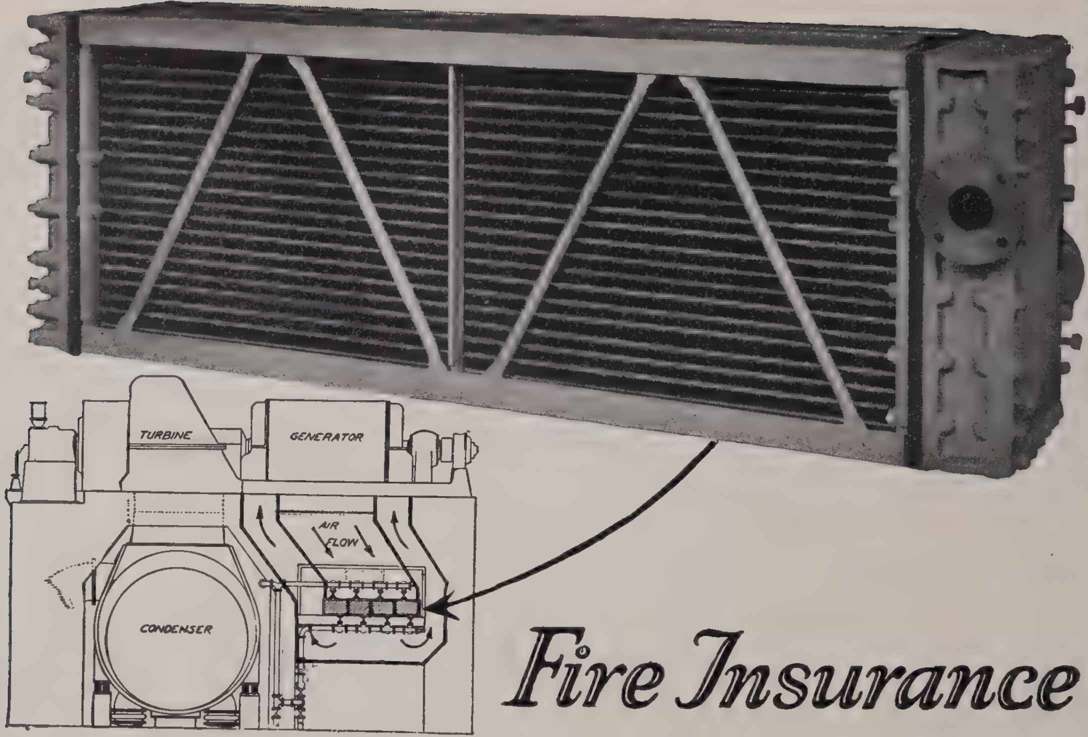

Fire Insurance

Protect your generators with

G-E Surface Air Coolers

The G-E Surface Air Cooler operates in a closed system. The volume of air in such a system can support but a small amount of combustion. A fire started in the generator windings will be immediately smothered.

The generator is protected also against dirt and other harmful agents coming in contact with the insulation, because the closed system contains only clean, dry air and re-circulates it over and over.

Still other advantages of the closed system of ventilation are:

Generator losses heat feed water
Less noise from circulating air
Very simple air ducts

G-E Surface Air Coolers are easily installed for existing equipment. By all means include them in new installations.

Bulletin 45609

Exclusive G-E Features

- Helically wound and shouldered copper fin designed for maximum heat transfer.
- Extremely simple multi-pass water box with removable cover plate.
- Individual tubes easily removed and replaced.
- Non-corrodible, muntz-metal tube sheets, one inch in thickness.
- Sherardized bolts and frame.
- Heavy, rigidly welded, structural steel frame.
- Simple, but rigid, tube support at center of tube bank.

35-7B

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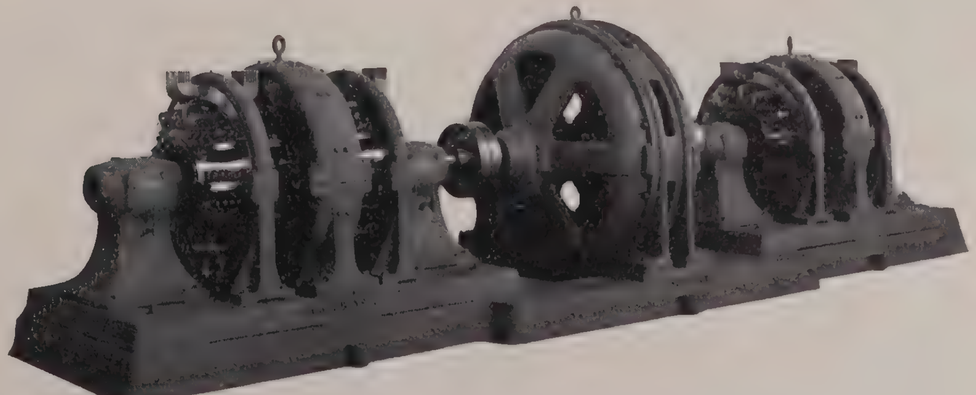

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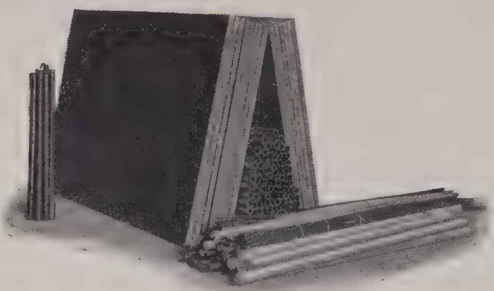

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SPEER—the name of quality

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"Buffalo" for permanent satisfaction

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"Twelve Buffalo Forge Turbo-Conoidal double width, double inlet fans furnish the forced draft for the underfeed stokers. Eight of these fans, used on 1263-h.p. boilers, were installed in February, 1918. The other 4 fans were put into service in March, 1921.

"The fans must operate continuously at times for 72-hour periods, but they have performed satisfactorily and easily deliver their rated air capacity. With our automatic stokers they enable us to get three or four times the horse-power that would be possible with the old-fashioned hand firing. In addition, the stokers and fans insure more perfect combustion, which means real fuel economy.

"Buffalo Forge Fans are being installed throughout in the big new Miami Fort Station of the Columbia Power Co.—an affiliated company."

This information is from D. S. Brown, Supt. of Production, Union Gas & Electric Co., Cincinnati.

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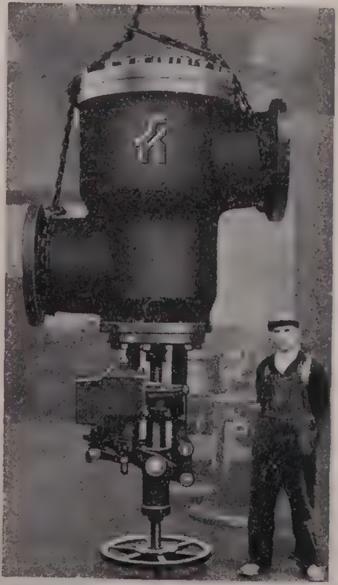

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Offset feature reduces pressure losses

Ask Valve Dept. for details

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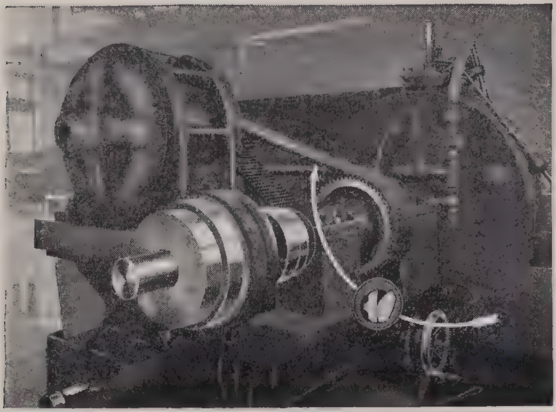
THE MORSE ROCKER JOINT



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Driver, 870 r.p.m.; driven 557 r.p.m., 30-inch centers

Positive, Flexible Power Transmission

Morse Silent Chain Drives provide a positive, flexible transmission for all types of power drives between parallel shafts.

With a friction loss of less than one and one-half percent, they are being run at speeds from 6,000 to 250 r.p.m. or slower, and are transmitting from one-quarter to 5,000 h.p. They are as flexible as belts, positive as gears, and more efficient than either.

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579

Don't Hesitate

The man who hesitates may not be lost, BUT

He is surely missing some of the good things

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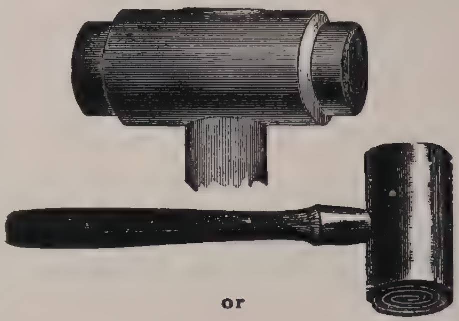
Hide Faced Hammer



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Raw Hide Mallet

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We know that you will be satisfied and we will gain a new customer.

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Holbrook Raw Hide Co.
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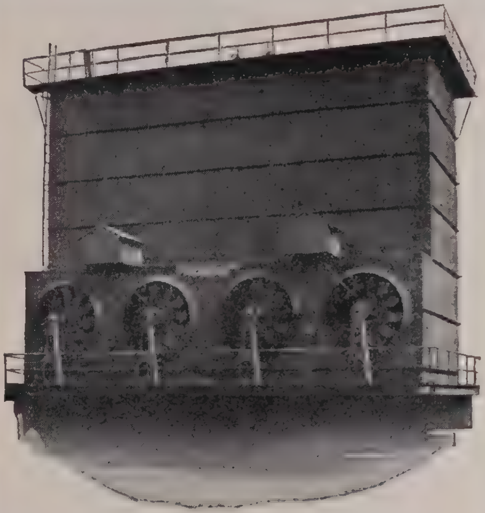
Manufacturers of Hide Faced Hammers and Raw Hide Mallets



Cool Condenser Water on Hot, Humid Days

And on all other days this C. H. Wheeler Forced Draft Cooling Tower, re-cools the circulating water, resulting in a high vacuum being carried the year around.

Where space is available a Natural Draft Cooling Tower may be installed.

Let us solve your condenser water re-cooling problem.

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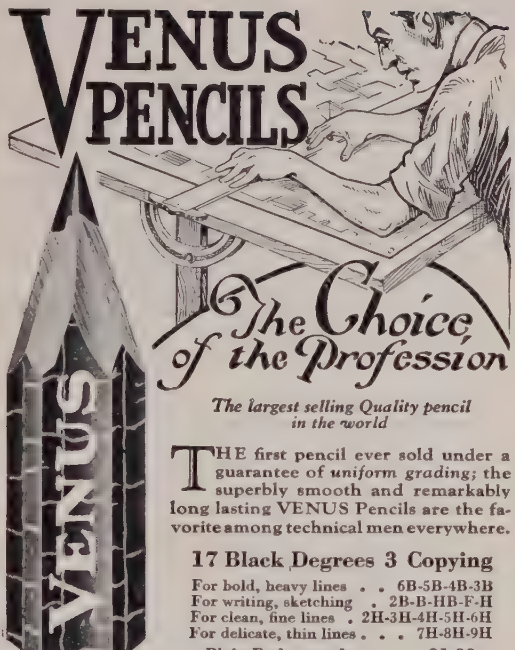
"C. H. Wheeler of Philadelphia"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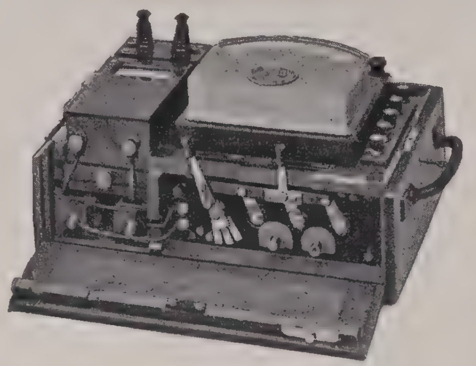

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("S-H" Standardizing Set)

For checking and calibrating portable and switchboard electrical instruments.

Makes comparisons by means of a Precision Millivoltmeter against a standard cell. Direct reading in volts and amperes using precision shunts and multipliers. Entirely self-contained and portable—weighs about 25 pounds.

Anyone of ordinary skill can operate this Industrial Potentiometer and can calibrate instruments *as accurately as the scales of the instruments under test can be read.*

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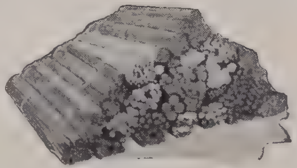

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for all types of boilers

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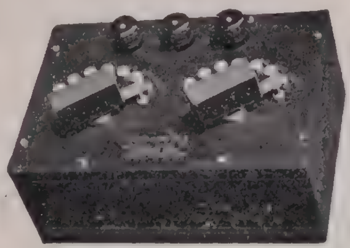

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TYPE 210

An instrument of great convenience for bridge measurements when used in conjunction with suitable standards of resistance, inductance or capacitance.

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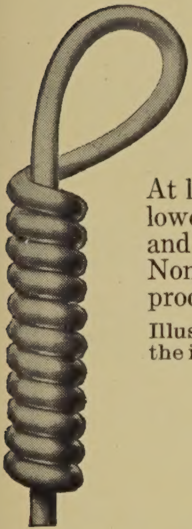
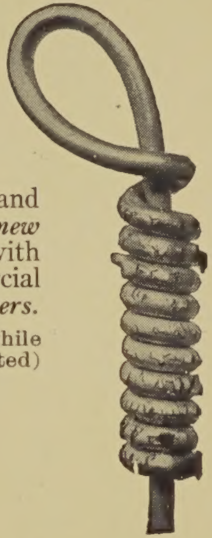


At last the Telephone and Electrical Industry is assured longer life and lower maintenance on galvanized wire construction through our *new* and *improved* patented Galvanizing Process, which insures a wire with Non-Peeling and Non-Cracking Zinc Coating. Now in full commercial production. Carried in stock by Representative *Supply Jobbers.*

Illustration at right shows what happens to old process galvanizing, while the illustration at left shows assured results of CRAPO PROCESS—(patented)



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Standard or Commercial, Siemens-Martin, High Strength and Extra High Strength Grades

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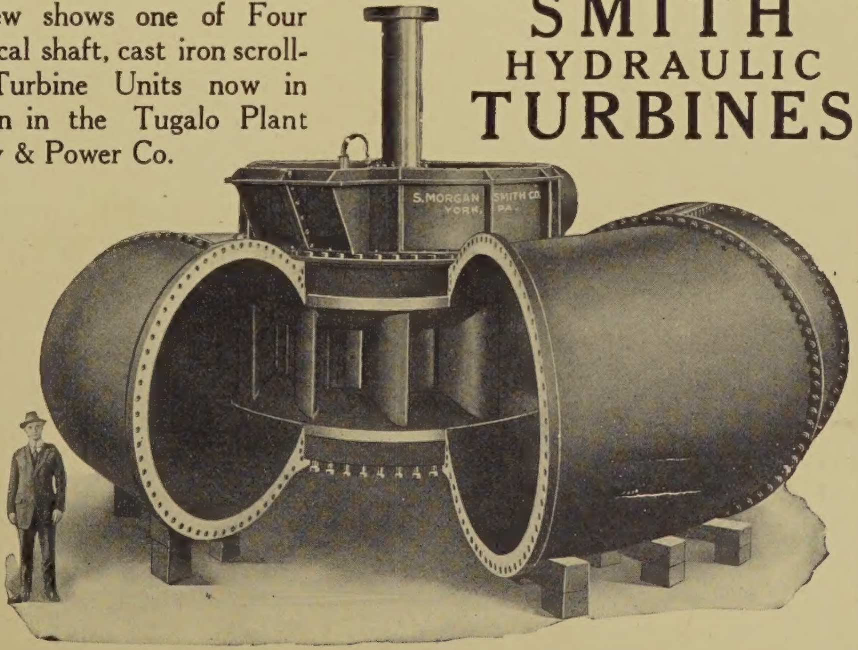
Accompanying view shows one of Four single-runner, vertical shaft, cast iron scroll-case Hydraulic Turbine Units now in successful operation in the Tugalo Plant of Georgia Railway & Power Co.

Each turbine develops 22,000 H.P. at 171.4 Rev. under 150 ft. head and is direct-connected to a 12,500 kw. General Electric Generator.



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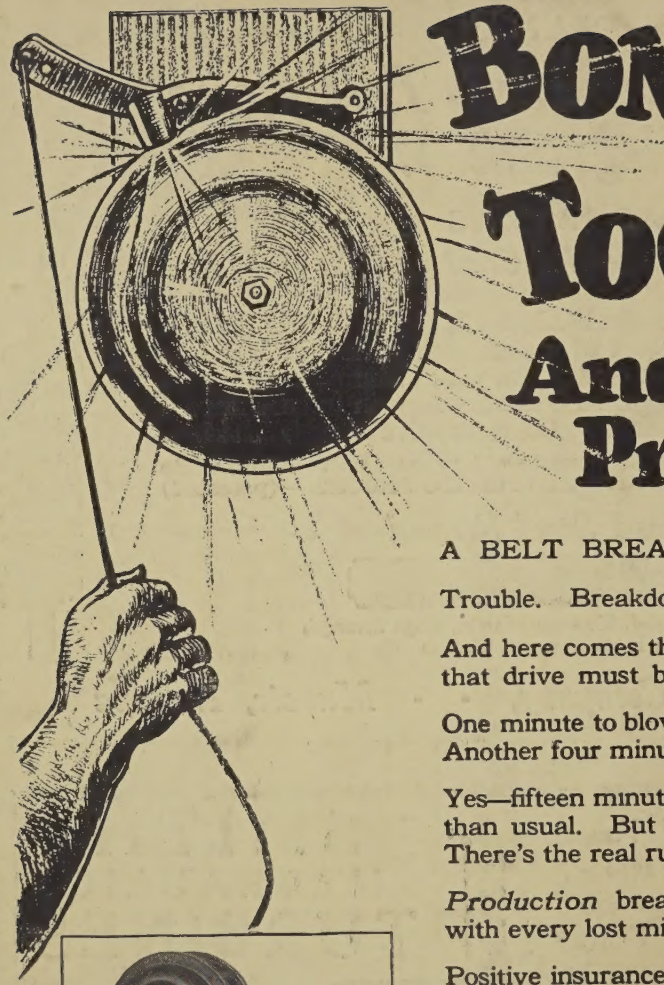


BONG BONG! or TOOT TOOT! And "Bang" Goes Production

A BELT BREAKS. A whistle blows or a bell rings.

Trouble. Breakdown. Grief.

And here comes the belt man on the hop, skip and jump—that drive must be fixed and fixed in a hurry.

One minute to blow or toot. Ten minutes to fix the break. Another four minutes for conversation.

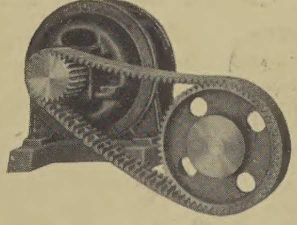
Yes—fifteen minutes would be small time loss—much less than usual. But that's not all. *Production stopped.* There's the real rub.

Production breaks when drives break. Costs mount with every lost minute.

Positive insurance against this kind of broken production is easily bought. It's permanent protection, too. Use Link-Belt Silent Chain Drives!

Many Link-Belt *Silent Chain Drives* have been in *continuous* operation for ten, fifteen, twenty years. They are still giving excellent service.

Flexible as as a belt—positive as a gear—more efficient than either, these Silent Chain Drives deserve a place in your plant. Then production breaks cease—and in a few years' service, Silent Chain Drives will more than pay for themselves. Send for price-list Data Book No. 125.



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Link-Belt Silent Chain Drives, from ½ to 10 H. P., in almost any speed ratio from 1 to 1 up to 7 to 1, can now be obtained from stock from a Link-Belt Distributor near you. Send for Book 725. or name of your nearest distributor

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